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Statistical process control techniques for the telecommunications systems manager

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THESIS

Statistical Process Control Techniques for
the Telecommunications Systems Manager

by

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Lee W. Schonenberg

March, 1992

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The purpose of this thesis is to provide personnel, who are undergoing Total Quality Leadership (TQL) implementation at their telecommunications-related commands, an understanding of Statistical Process Controls (SPCs) and their potential application to telecommunication issues. Basic SPC tools common to all total quality programs are discussed. Advanced SPC methods including Analysis of Means (ANOM), Analysis of Variance (ANOVA) Weibull analysis and Taguchi methods are also presented. Selected SPC training programs of both the U.S. Navy and the commercial telecommunication industry are examined. A case study of a telecommunication-related issue is provided to demonstrate an integrated approach to the use of SPCs.

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Statistical Process Control Techniques for the Telecommunications Systems Manager

by

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ABSTRACT

The purpose of this thesis is to provide personnel, who are undergoing Total Quality Leadership (TQL) implementation at their telecommunications-related command, an understanding of Statistical Process Controls (SPCs) and their potential application to telecommunications issues. Basic SPC tools common to most Total Quality programs are discussed. Advanced SPC methods including Analysis of Means (ANOM), Analysis of Variance (ANOVA), Weibull analysis and Taguchi Methods are also presented. Selected SPC training plans for both naval telecommunication commands and commercial telecommunication industry are examined. Finally, a case study of a telecommunications-related issue is provided to demonstrate an integrated approach to the use of SPCs.

TABLE OF CONTENTS

I. INTRODUCTION

A. BACKGROUND

The role of Statistical Process Control (SPC) in the Total Quality Leadership (TQL) philosophy will be discussed briefly as an introduction to the thesis to ensure the reader has the proper perspective of the overall TQL philosophy. TQL theory stipulates that all functions can be broken down into processes that are subject to variations due to specific causes. Once identified and subjected to a system of constant improvement, these processes increase in quality and decrease in cost. The Navy is striving for a system under which management decisions are based on data from process analysis rather than just experience, on fact more than intuition, on quality and strategic foresight rather than simple, short-term cost savings (Howard 1991). SPCs are the basic working tools of TQL. Because the key SPC's are required to be understood and used at the lowest levels possible in a process, they are necessarily simple. More sophisticated SPC's exist at higher levels and are largely process specific.

B. SCOPE

The purpose of this thesis is to provide to personnel, who are undergoing TQL implementation at their telecommunications-related command, an understanding of SPCs and their potential

applications to telecommunications issues. Areas of discussion include basic and advanced SPC tools, quality cost analysis, and SPC training plans of the U. S. Navy and the telecommunications industry.

C. THESIS OUTLINE

This thesis will be presented in a manner to afford an individual, with no experience in TQL or communications, a reasonably detailed understanding of SPC's and their potential for application in the communications field. Chapter II briefly discusses basic TQL theory. Chapter III discusses basic SPC tools that are common to most total quality organizations. Chapter IV highlights more sophisticated tools used in the communications industry and presents a quality cost model. Chapter V examines selected SPC training programs of the U. S. Navy and the telecommunications industry. The final chapter will summarize the findings and present a sample case study of a communications process.

II. TQL THEORY

A. INTRODUCTION

The purpose of this chapter is to provide the reader with a general understanding of the framework of the TQL philosophy present in the Navy and how SPCs fit into it. Key issues addressed include process definition, the concept of variation, and finally a discussion of the Total Quality Leadership management model, the Plan, Do, Check, Act (PDCA) cycle.

B. BACKGROUND

The Navy's TQL program has its roots in the quality philosophy of W. E. Deming, an American statistician widely regarded as one of the driving forces behind the rebirth of Japan as an economic world force. The program's impetus was in the Naval Aviation Depot (NAD) system to solve problems of industrial inefficiency. Based largely on the success of TQL at NADs and Naval Supply Centers, and the forced reality of budget cuts demanding more efficient operations, the Navy is in the process of implementing TQL on a fleet-wide scale (CNO 1991).

C. PRINCIPLES OF TOTAL QUALITY LEADERSHIP

The basic premise of TQL is that through constant analysis and improvement of processes, quality will be improved and costs will be reduced. A process can be defined in two ways:

- A series of operations or steps that results in a product or service.
- A set of causes and conditions that repeatedly come together to transform inputs into outcomes (Nolan 1990).

Examples of telecommunications-based processes are the establishment of a satellite communication link or an AUTODIN message transmission. To date, the Navy largely relies on end-inspections to ensure the quality of the products and/or services it provides. This system is reactive, inefficient and focuses only on the end-product of the process. TQL advocates a more proactive and efficient method, one concentrating on improving the process which, in turn, improves the product.

For a process to be effectively analyzed and improved, hard data and facts about the process are required. SPCs address this need to collect and correlate data.

D. STATISTICAL PROCESS CONTROLS

For the purpose of this thesis, the term "Statistical Process Controls" collectively refers to statisitically based methods used to achieve quality control of a process. These

methods will be addressed in depth in the third and fourth chapter.

SPCs are tools that assist management in diagnosing processes by breaking them down to more manageable and understandable units. They range in complexity from the quite simplistic cause and effect diagram to highly complex computer based analysis programs used to monitor and integrate process performance. Paramount to the success of SPCs is the ability to select meaningful and measurable goals that accurately reflect the actual state of the process being analyzed (Dockstader 1988).

SPCs have their origins in the manufacturing industry where tolerances and specifications are more tangible and easy to measure. While certain facets of the Navy are manufacturing related, the Navy is more characteristic of a service industry. A service industry is one that provides a service rather than a physical product. An example of this is the communication services provided by a Naval Computer and Telecommunication Area Master Station (NCTAMS). Only recently have SPCs been applied in service industry settings. This is due to the difficulty in defining and then measuring the goals that define quality in services. Referring back to the satellite communication link example, the measurement of the "quality" of the connection typically involves something less concrete than the actual physical measurement of a bolt. To be successful, intermediate indicators must be definable and

measurable. With this accomplished, applying SPCs to processes provides management with data to begin to answer the following questions:

- Is the process stable or unstable?
- If unstable, what is the cause of the variation?
- Can the variation be classified as common cause or special cause?

Thus, in order to begin to answer these questions, a clear understanding of variation, its impacts and its causes is necessary.

E. VARIATION

Variation is present in all aspects of life. Variation can be defined as the *fluctuation* of a process (AT&T 1990). An example of variation is the fact that identical AUTODIN message transmittal times range from minutes to hours. The mathematical measure of process variation is the standard deviation. Standard deviation is defined as the dispersion of measurements relative to the predicted overall average of the population (Ryan 1989). Figure 1 graphically illustrates the concept of variation (AT&T 1990).

A major function of any manager is to make decisions. Often these decisions involve the analysis of a process that is subject to variation. It is the job of the manager to interpret the pattern of variation present in the process and

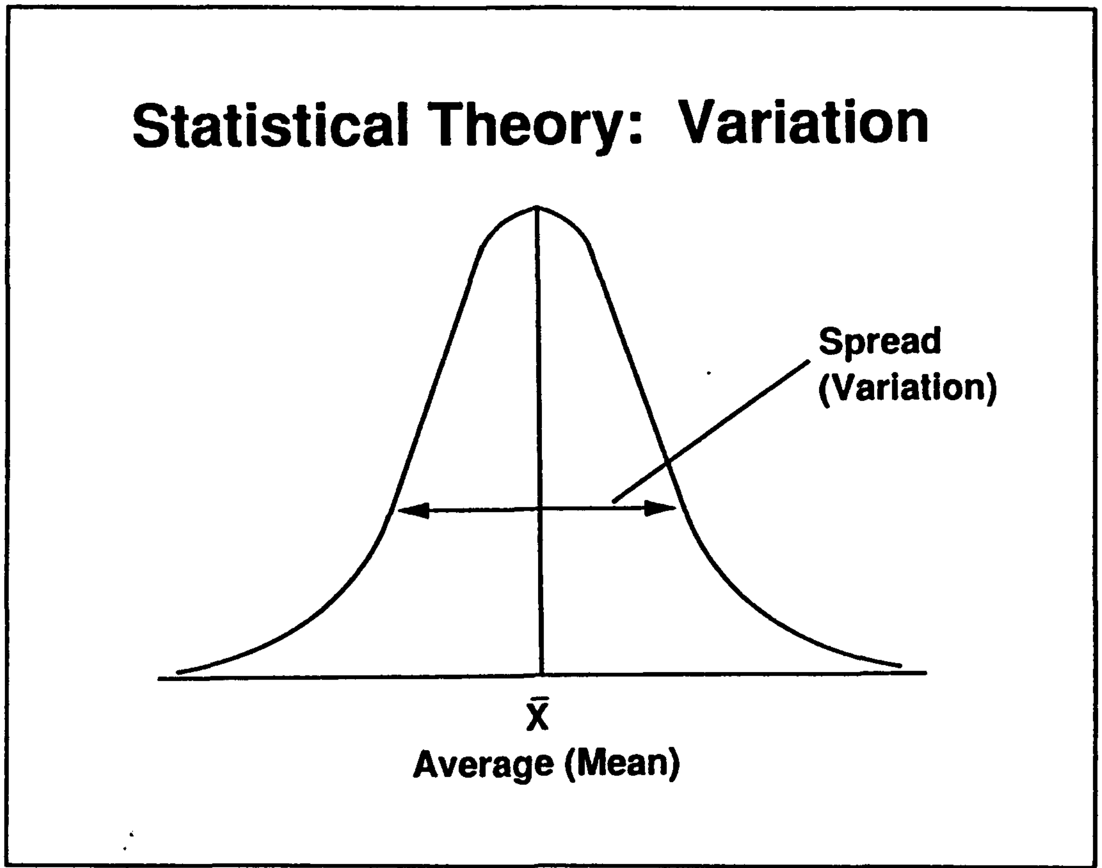

Figure 1 Variation

to decide whether or not to take corrective action. Walter Shewhart of Bell Labs, in his fundamental studies of process variation, discovered that variation can be broken down into two types or categories: common cause and special or assignable cause variation.

1. Common cause

Common cause variation is variation inherently involved in a process and affecting <u>all</u> aspects of it (Nolan 1990). Examples of common cause variation are a crowded room or an insufficiently manned work area. W.E. Deming estimates

that common cause variation accounts for over 85 percent of process problems, with the remaining 15 percent beginning attributed to special cause variation (Scherkenbach 1990).

2. Special cause

Special or assignable cause variation is the result of spurious external and/or internal factors that are not constant contributors to the process (Nolan 1990). They can be viewed as actions that arise only because of special circumstances. Examples of special cause variation in a process is the increase in message transmittal time due to the presence of a new radioman on a shift or an increase in message traffic resulting from the arrival of a battle group in a communication area. The presence of the new radioman is the "assignable" cause of the variation in transmittal times. Frequently, special cause variation can be easily corrected by the people in the process most directly involved in its operation. The shift foreman can provide insight to the new radioman to bring him up to speed. Management can also implement changes in the process to remove the source of the special variation. An example of this is the implementation of a familiarization training program for all new personnel prior to their first shift.

Variation does not always have a negative effect on a process. The special variation example of an increase in message transmittal time due to a new radioman could just as

easily have been a decrease in message transmittal due to the presence of an additional "old" hand.

Variation is omnipresent, thus a manager can only hope to reduce it or to make it manageable. To do this the process must be "stable" or predictable, totally devoid of any special cause variation. The SPC tool that aids in the determination whether a process is dominated by common cause or special cause variation is the control chart. It will be looked at in depth in the third chapter. The means to effectively employ SPCs and provide management with a tool to ensure constant process improvement is the PDCA cycle.

F. PDCA CYCLE

TQL emphasizes the major role that managers have in achieving quality and productivity improvement for an organization (Dockstader 1988). The means to achieve these results is through the use of the Plan, Do, Check, Act cycle as depicted in Figure 2 (Dockstader 1988). Developed by Walter Shewhart, the PDCA cycle provides management with an effective, analytical model by which to guide the process improvement cycle. Each phase of the cycle addresses issues that impact upon a process. SPCs provide the means to collect and analyze process data, enabling managers to make more educated decisions.

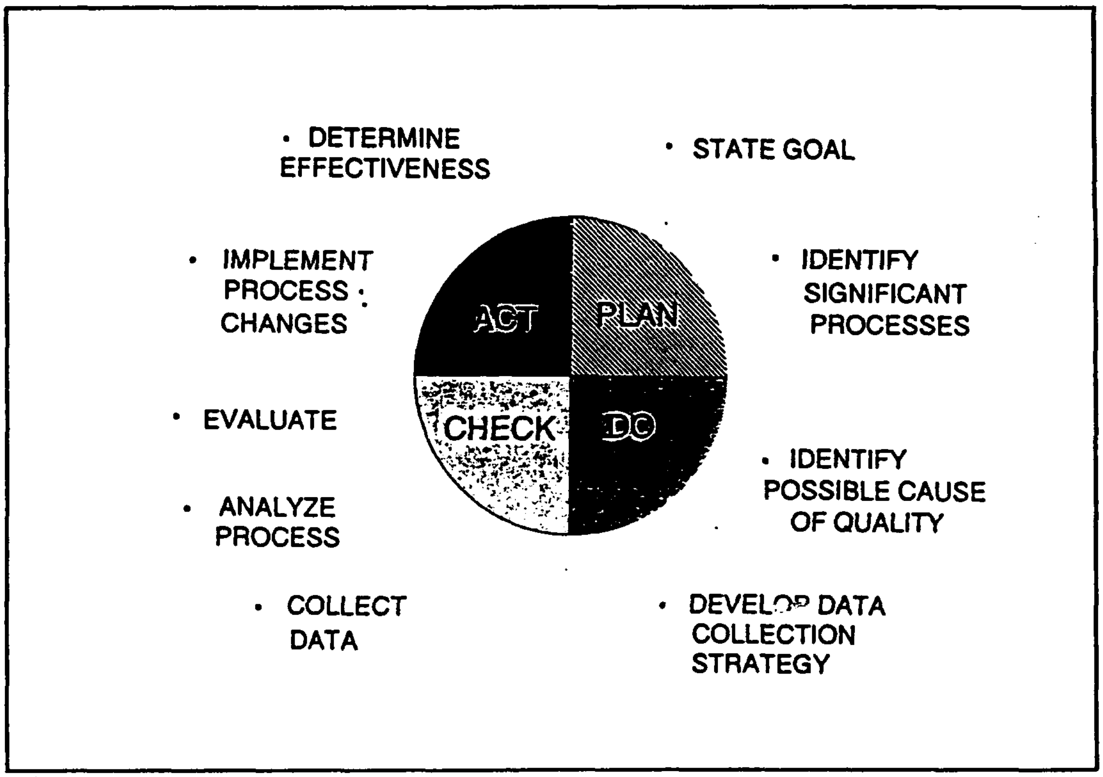

Figure 2 The PDCA Cycle

1. Plan Phase

The primary objective of the plan phase is the identification of critical product or service requirements of the customer (Dockstader 1988). Since quality in the TQL sense is defined by the customer, several questions must be answered prior to requirement identification. They include:

- Who are our major customers?
- What do they consider our most important products?
- What is their attitude towards the product/services we provide?
- What parts of the product process have the greatest impact on the end product?

- What changes to the process need to be made to effect a change?

Information gained from these questions leads management to the development of quality goals. These goals should be clearly defined and readily measurable. An example of such a goal is the reduction of set up times for a satellite communication link. When using SPCs to analyze a process, it is important to define measurable goals so that their achievement can be verified by data, not subjective opinion.

A useful SPC tool to aid in the Planning phase is the flowchart. The flowchart aids in process definition by graphically portraying the interrelations of operations and decisions necessary to create a process. By providing a "level playing field" of process definition, the flowchart removes any ambiguity in the planning process.

2. Do Phase

The primary objective in the Do phase is to collect data to aid in process improvement (Dockstader 1988). Acting on the quality goals defined during the Plan stage, management, working with personnel familiar with the process being analyzed, set about the task of identifying specific variables directly related to quality. Once these variables have been identified, management must decide on effective forms of measurements to allow these variables to be charted.

As previously mentioned, this task is extremely difficult outside of a manufacturing environment. Following the identification and definition of quality variables, a data collection plan must be formulated. A well developed data collection plan ensures comprehensive data coverage of the process. This data provides a picture of what is currently happening in the process, forming a baseline for present and future analysis of change implementation. Flowcharts and cause and effect diagrams are specific SPC tools that are useful in achieving these objectives.

As in the Plan phase, the flowchart aids in breaking down the process into more manageable units. The cause and effect diagram assists in the task of identifying specific causes and variables that effect the outcome of the process. It shows the relationship between sets of possible process variables and a specific process result (Ishikawa 1983). In-depth development and utilization of this tool will be covered in Chapter III. Armed with data concerning the baseline state of the process to be analyzed, the Check phase begins.

3. Check Phase

Process data collected during the Do phase is analyzed to determined specific process causes in the Check phase. Several SPC tools are used to summarize and analyze the data for management. Pareto charts relate cause functions to their frequency of occurrence in the process. Histograms are used

to create a picture of the frequency distribution of the process. Run charts relate elapsed time to process performance. Control chart analysis forms the basis of system performance and correlation. Decisions concerning the cause of the variation, its type, significance, and the formulation of corrective methods are made during this stage. The actual implementation of corrective measures is accomplished in the Act phase.

4. Act phase

In the Act phase, change is introduced into the system based upon interpretation of SPC data. Depending on the determination of the type and source of variation, two actions can result. If the process has been determined to be under the influence of special causes, action towards correcting the process can be accomplished at the worker level. A process dominated by common cause variation requires higher level management to implement change as the entire process is effected rather than just more isolated sections as is the case for special cause variation. The far reaching effects of common cause variation warrant a prudent application of change on a small scale basis rather than a company or department-wide scale. This is to prevent further complications to the process and the department in the event that the corrective actions compound rather than correct the problems present in the process.

Once changes have been implemented, data is collected using the system installed in the Act phase, to ensure the implemented change has the required effect. Two possible situations can arise. The change may have the desired effect, whereby process monitoring continues via SPC tools, or the change fails, resulting in PDCA cycle resumption. Either situation requires the continued use of SPCs to monitor the state of the process. Figure 3 provides a summary of the PDCA cycle and the SPC tools that are commonly used in each phase.

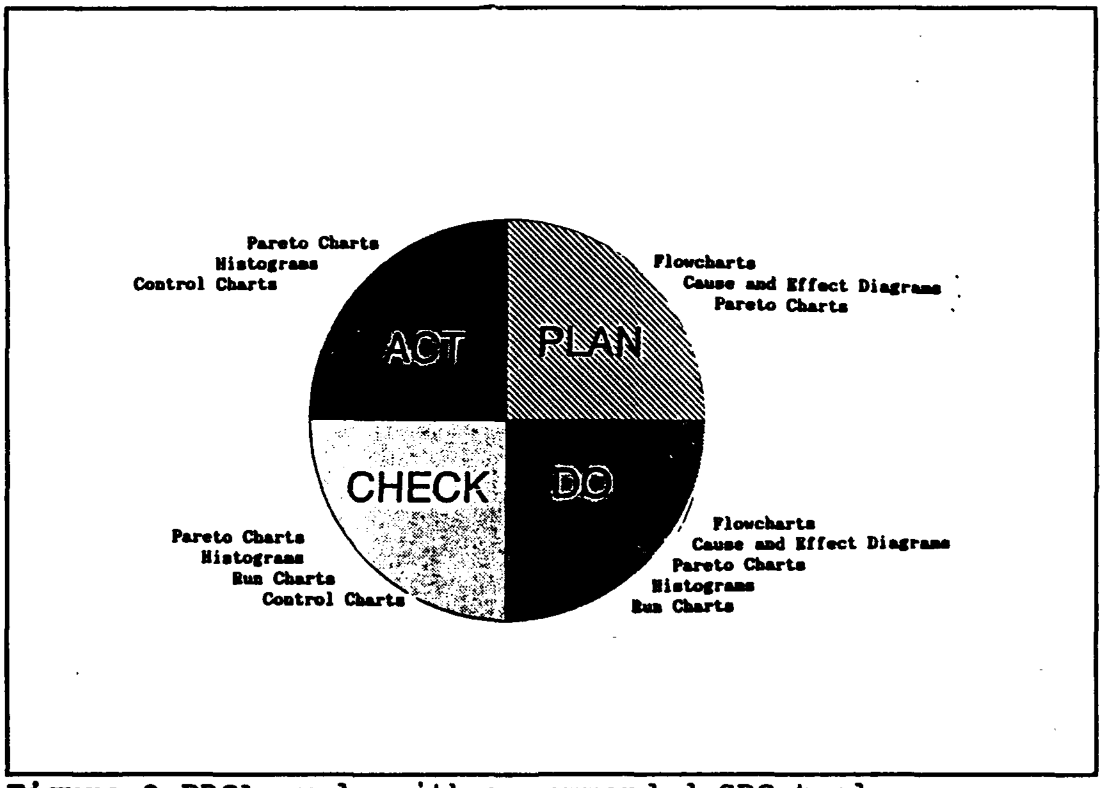

Figure 3 PDCA cycle with recommended SPC tools

III. BASIC QUALITY IMPROVEMENT TOOLS

A. GENERAL

The purpose of this chapter is to provide the telecommunications manager with an understanding of the capabilities of SPCs. Though simplistic in nature, SPCs provide the manager with powerful tools to collect and analyze data concerning process activities. Implicit in the discussion of these tools is the requirement to link them with a sound quality philosophy and management strategy. Similarly, the use and applications of SPCs should be monitored by a professional statistician in all but the most trivial cases (Deming 1986).

B. FLOWCHARTS

Imperative to making significant improvement in a process is an exact understanding of the complete process. The first step towards this is often a flowchart. Flowcharts are usually developed by a cross functional action team such as a Process Action Team (PAT). Central to the clarity of the flowchart is an understanding of both how the process should work and how it really works (Walton 1986). Flowcharts serve several useful purposes (Walton 1986):

- Redundant operations are identified.

* Knowledge and awareness of stakeholder needs are increased.

* Cross-functional boundaries are bridged.

* Participants view their role in a macro sense.

* Inefficiencies are identified by differences in the way the process should work and how the process really works.

Flow charts are typically arranged as a series of boxes, diamonds and circles that indicate actions, options, and results, respectively. Figure 4 illustrates an example flowchart for the approval and transmission of a naval administrative message.

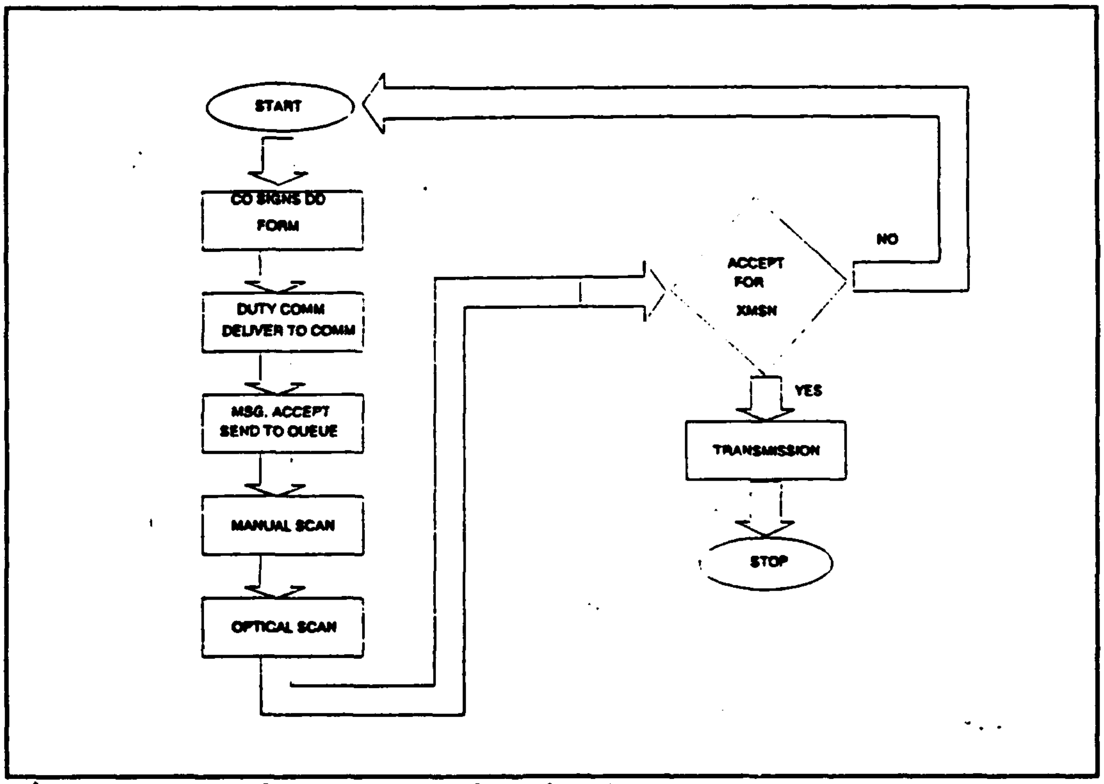

Figure 4 Naval Message Flowchart

C. CAUSE AND EFFECT DIAGRAMS

More commonly referred to as "fishbone" diagrams, cause and effect diagrams help a team identify both desirable and undesirable causes of a specific result or "effect". For example, the Japanese electric utility Kansai, used cause and effect analysis to reveal that workers sometimes drove transformer grounding rods into the ground to less than the required depth. They then urinated on the rods to temporarily provide a satisfactory resistance measurement for the rod. When the urine dried up, the rods were insufficiently grounded. After corrective measures were put in place to ensure that all transformer rods were sufficently grounded, the utility boasted an average power outage rate of seven minutes per year compared to typical values near 100 minutes per year (Walton 1991). In addition, the reserve requirements for the expensive transformers were significantly lower than other utilities as there were far fewer burn-outs over the year. Cause and effect diagrams are typically drawn up from cross functional group brainstorming sessions. Broad categories usually include materials, methods, manpower and machines (Walton 1986). Cause and effect diagrams provide several benefits (Walton 1986):

- The creation of the diagram is in itself educational.
- The working group tends to focus on a specific issue or "effect".

- The complexity of the problem is immediately apparent to group participants.

Figure 5 continues with the transmission of an administrative naval message. A delayed message at a communication center is the result and the causes are logically grouped according to man, machines, methods and materials. This example clearly illustrates how cause and effect analysis bridges areas of responsibility both within an organization and to other participating organizations in the process.

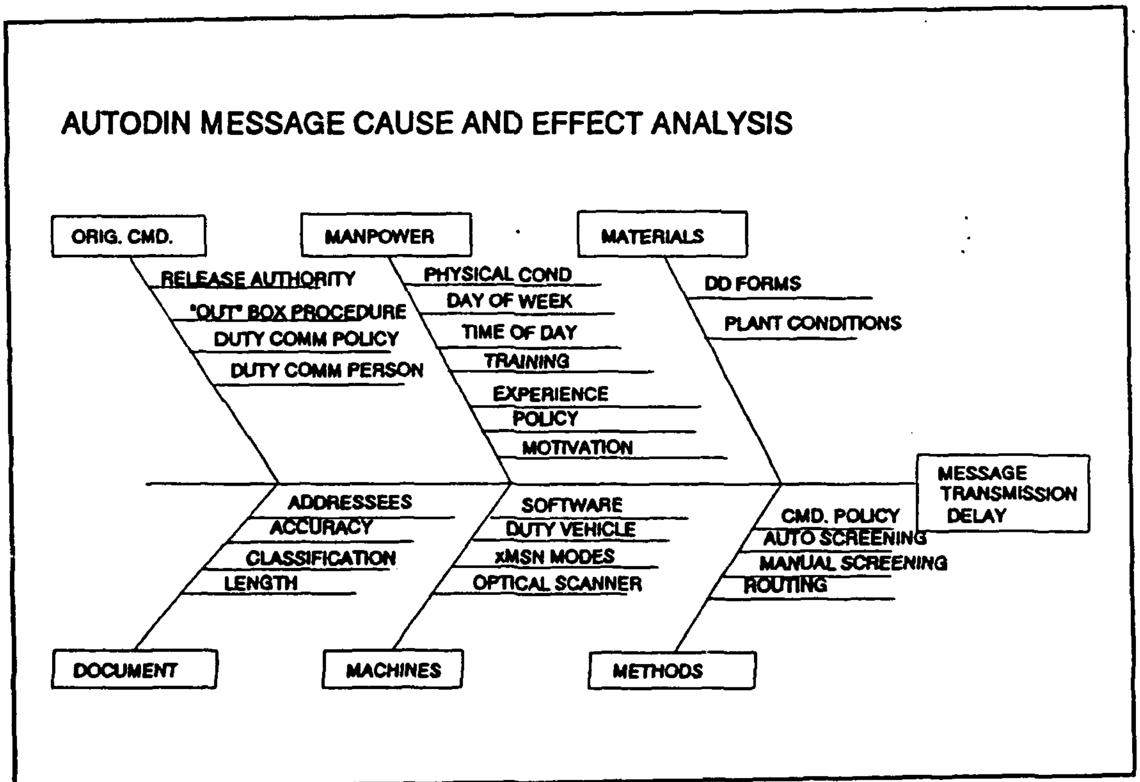

Figure 5 Message Delay Cause and Effect Diagram

D. PARETO CHARTS

Pareto charts display the number of occurrences of selected conditions that create a particular effect in rank order. Data is collected over a period of time and is displayed in bar chart format to illustrate the relative frequency of each condition from most frequent to least frequent (AT&T 1990). Benefits of the Pareto chart include:

- The most common causes are clearly illustrated.
- Presumptions about significant causes can either be validated or disproved.
- Seemingly immense problems with many causes can be narrowed to a reasonable number of key areas.

As an example of a Pareto analysis, the obstetrics staff at the West Paces Ferry Hospital in Atlanta was interested in increasing patient satisfaction and reducing morbidity and mortality rates by reducing the C-Section rate. Pareto analysis revealed that a startling 27% of all C-Sections were performed at patient request while another 13% were repeat C-Sections (Walton 1991). The customers apparently believed that C-Sections were routine procedures and that the old saw, "once a C-Section, always a C-Section" still held true. Although modern surgical techniques had negated this logic, it obviously was not public knowledge. To better inform their customers, the hospital embarked on an education campaign aimed at the patients and care providers to bring the customers' level of satisfaction up and the medical risks down

(Walton 1991). Figure 6 is a hypothetical example of a Pareto analysis of an administrative message rejection at a Naval Communication Station. The chart clearly suggests key areas in which to focus corrective efforts.

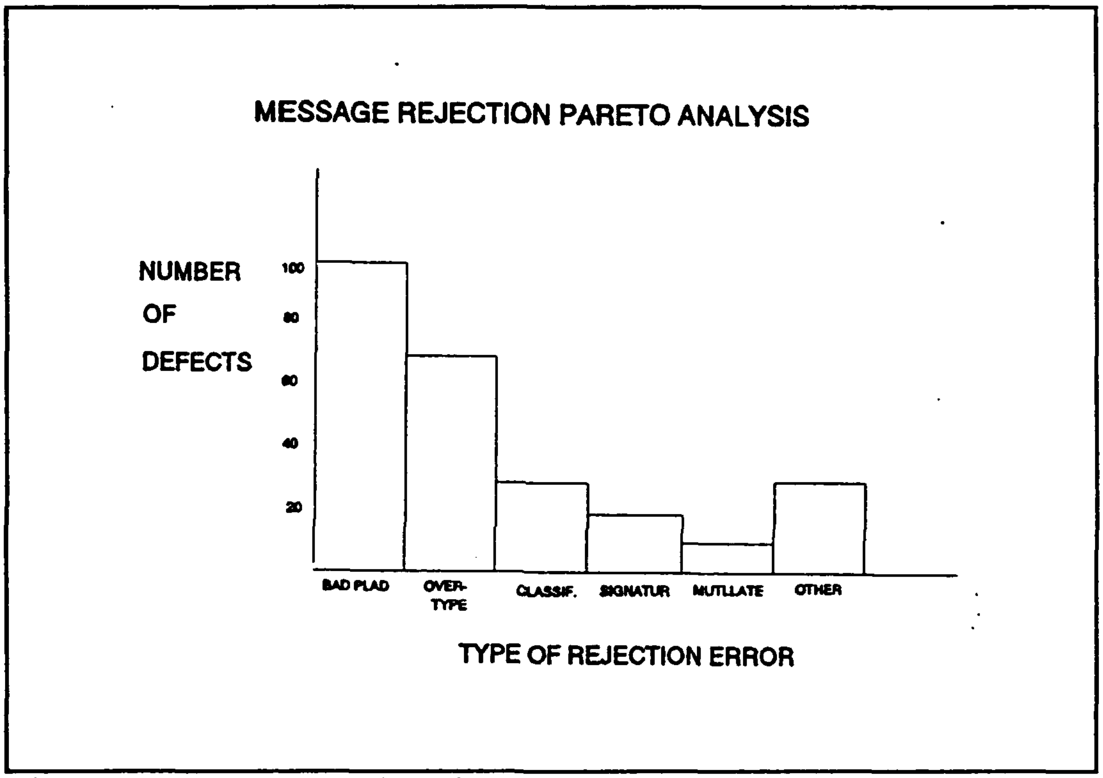

Figure 6 Message Rejection Pareto Chart

E. RUN CHARTS

Run charts display a measure of data over a period of time. While simple in format, they can easily show a trend. Run charts often press the originator to get more information to determine specific relationships. Figure 7 displays a relationship between the time to process a message once

received at a communication center and the elapsed time to transmission.

One might expect that shift changes every four hours were a factor. However, before rewriting the watchbill, the manager needs to make a detailed analysis of the process to determine the influence of other factors such as the training level of employees on particular shifts or the demands of supervisors during the execution of shift changes.

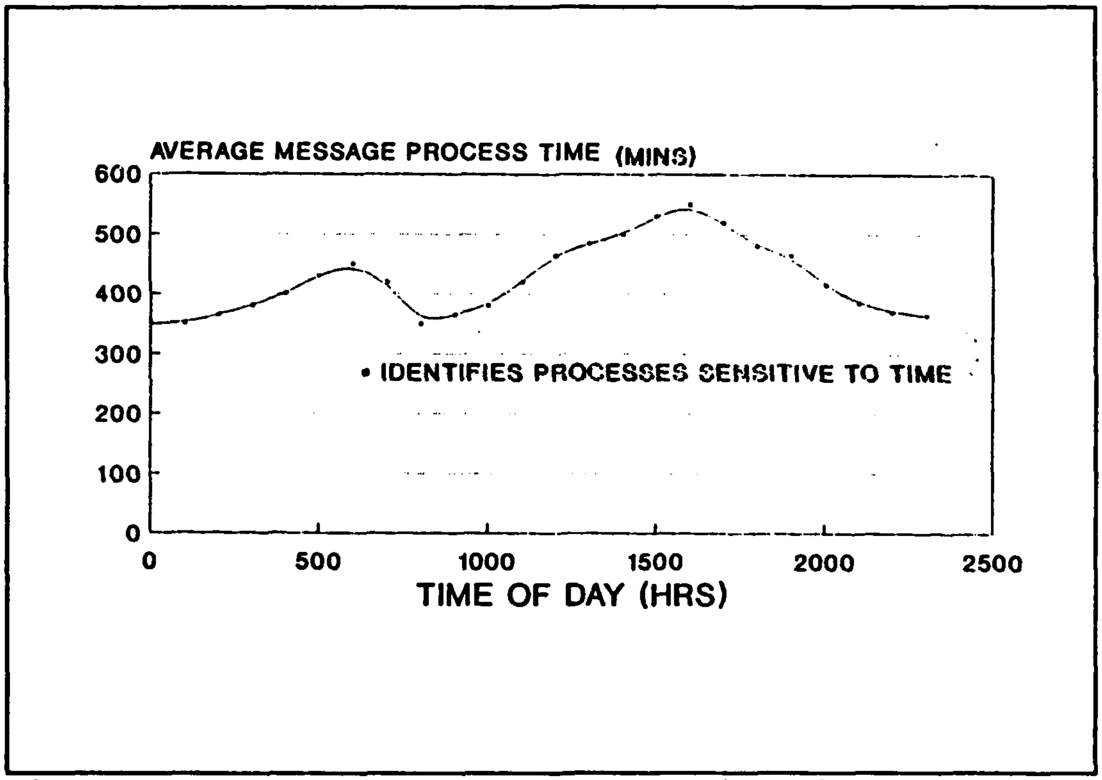

Figure 7 Run Chart of Message Processing Time

F. HISTOGRAM

A histogram is a picture of the frequency distribution of data. It depicts how frequently measures occur at each value.

Since a histogram does not show performance over time, it represents a snapshot of the process. As an example, the time to restore a satellite communication link is displayed in Figure 8.

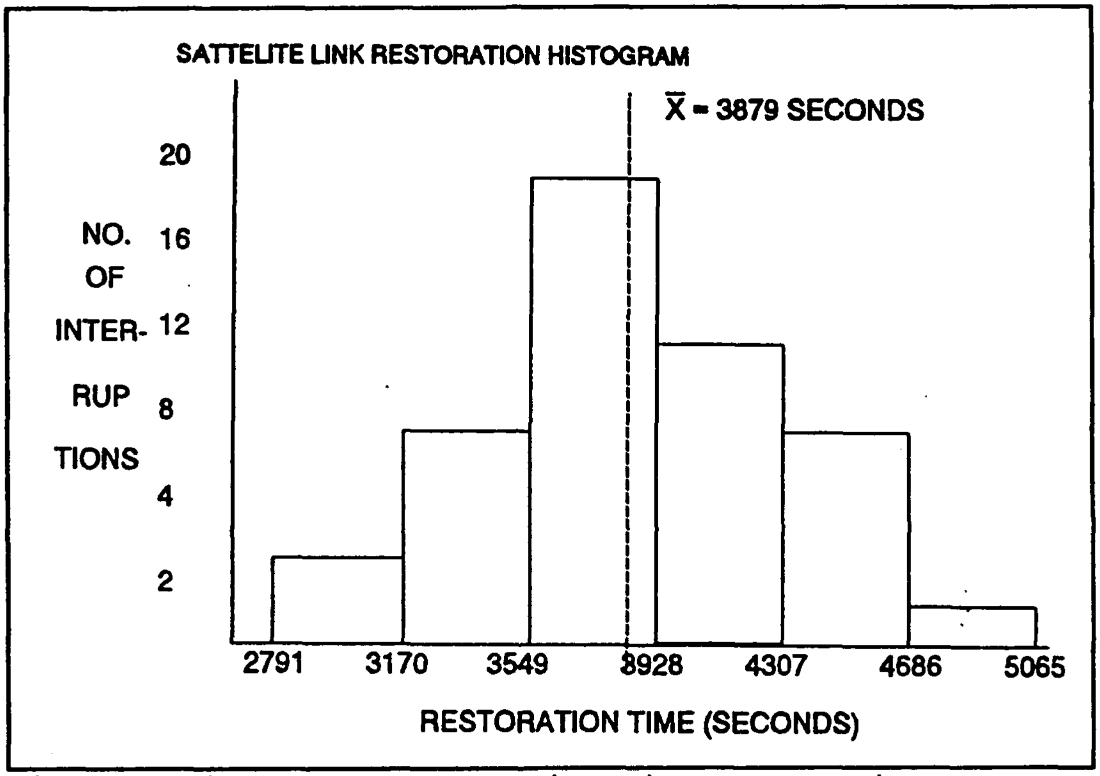

Figure 8 Histogram of Satellite Link Restoration

The X-axis shows measurement opportunities or "buckets" in which each observation falls. The Y axis shows the count total of measurements within each bucket. Variability can be revealed only if the buckets are relatively narrow. A generally accepted rule of thumb is that the number of intervals should approximately equal the square root of the number of measurements (AT&T 1990). Similarly, the Y axis

measurement intervals must be spread out enough to clearly indicate a difference in the observations.

The exact shape of the histogram is a picture of the frequency distribution of the data. The most typical shapes resemble a normal or "bell shaped" distribution. Features of a normal histogram include equal chances of data being above or below the mean and decreasing chances in each direction that data are very far away from the mean.

Histograms help the user understand the variation of a random variable. Key characteristics of the histogram are presented below (FP&L 1990):

- It is used for discrete data sets where the number of values in the set is large (10 to 20) and always for continuous data.
- Each bar or measurement opportunity bucket has the same range.
- The number of bars should increase as the number of data values increases.
- The shape of the distribution results in a specific interpretation and subsequent analysis.

G. ANALYSIS OF EXPLANATORY VARIABLES

1. General

A characteristic of a process to be controlled or improved is referred to as a response variable. Explanatory variables are influences on the process. There are two types of explanatory variables, group and regression. Group explanatory variables are qualitative variables that can be

classified or categorized. Typical analysis of group variables is performed with boxplots and a technique called Analysis of Means (ANOM). Regression explanatory variables can be quantified and interpreted with scatter diagrams and regression analysis. All these techniques are discussed in detail below.

2. Group Explanatory Variables

a. *Boxplots*

Group explanatory variables are typically analyzed with a boxplot. Boxplots represent a concise picture of a group's performance of a specific task. Figure 9 considers a process in which changes to a data base are analyzed (AT&T 1990). The time to enter the change is of concern to the manager. Specifically, he/she is interested if there is any correlation between the type of change made and the time it took to make the change. The data picture for each type of change is represented by a boxplot with the following common features (AT&T 1990):

- The line through the box marks the 50th percentile of the group distribution.
- Asterisks mark the range of the data.
- The borders of the box encompass data from the 25th to the 75th percentile.
- Finally, the "T" shaped features attached to each end of the box point to the 10th and 90th percentiles of the distribution.

Each boxplot gives an illustration of the relative variability and central tendencies of the various categories (AT&T 1990). Key discriminating factors include (AT&T 1990):

- The size of the box suggests variability. Larger boxes show large variability.
- The symmetry or lack of symmetry suggests information about the distribution of the data.

The apparent differences revealed in the box plots do not imply relative significance. Analysis of Means (ANOM) is a technique that is very useful in testing for statistical significance. ANOM is discussed in Chapter IV.

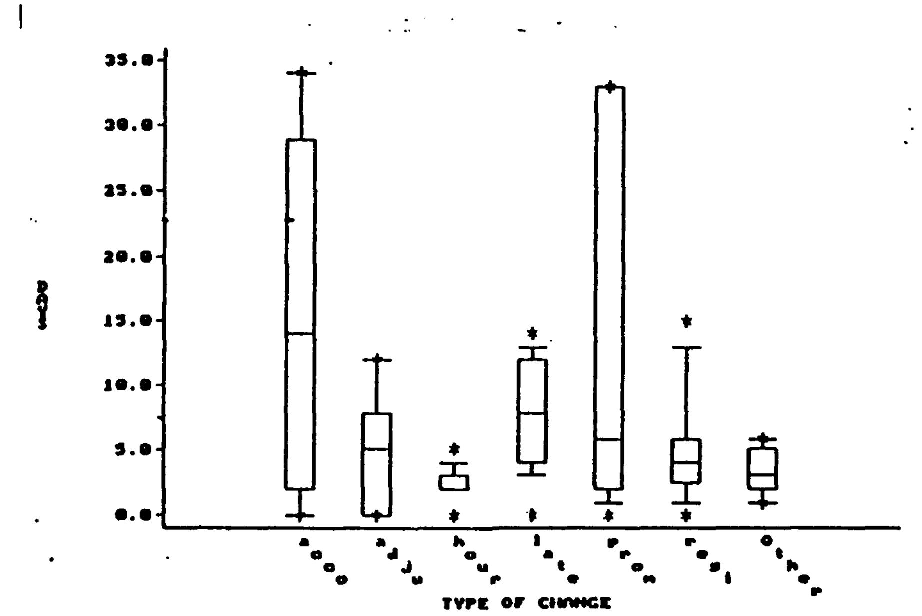

Figure 9 Boxplot of Change Processing Time

3. Regression Explanatory Variables

a. *Scatter Diagrams*

Scatter diagrams show how a response variable changes as the values of an explanatory variable change. An explanatory variable furnishes quantitative information about each sample. Using a telephone hotline time to pickup as a response variable, a relationship can be shown about the perceived timeliness of the line pickup. This relationship is displayed in Figure 10 (AT&T 1990). The resulting scatter diagram shows that the data points tend from the bottom left to the top right of the chart. Detailed modeling and interpretation of scatter diagrams is called regression analysis.

b. *Regression Analysis*

Regression analysis considers the distance between points and places a line through the points so that the sum of the squared vertical distances of all points from the line is minimized. Interpretation of this analysis involves three relationships.

First, the confidence of the line represents a degree of certainty that the two variables exhibit a linear relationship. Confidence bands illustrate a specific percentage of observations within set limits. The tighter the confidence band, the stronger the correlation between the two variables. The specific measure of the correlation is known

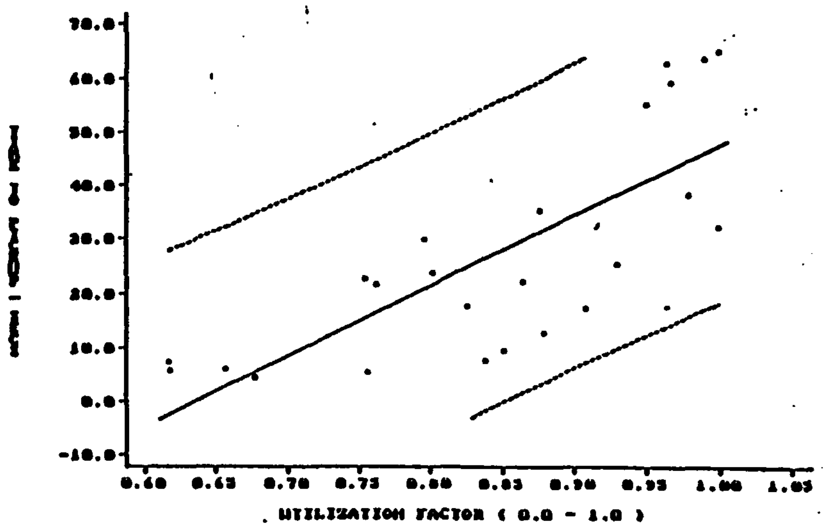

Figure 10 Scatterplot of Hotline Time to Pickup

as a correlation coefficient. It varies in value from +1 to -1 and carries the symbol "R". Values close to +/-1 suggest a strong correlation (AT&T 1990).

Second, the steepness or slope of the regression line shows how much one variable will change as the other variable is changed. Steep slopes reflect strong influences (AT&T 1990).

Finally, regression line orientation indicates the nature of the correlation. A line that tends from upper left to bottom right is a negative correlation that indicates an inverse relationship between variables. Conversely, a line that tends from bottom left to upper right shows a positive

correlation that suggests that an increase in the first variable will result in an increase in the second variable.

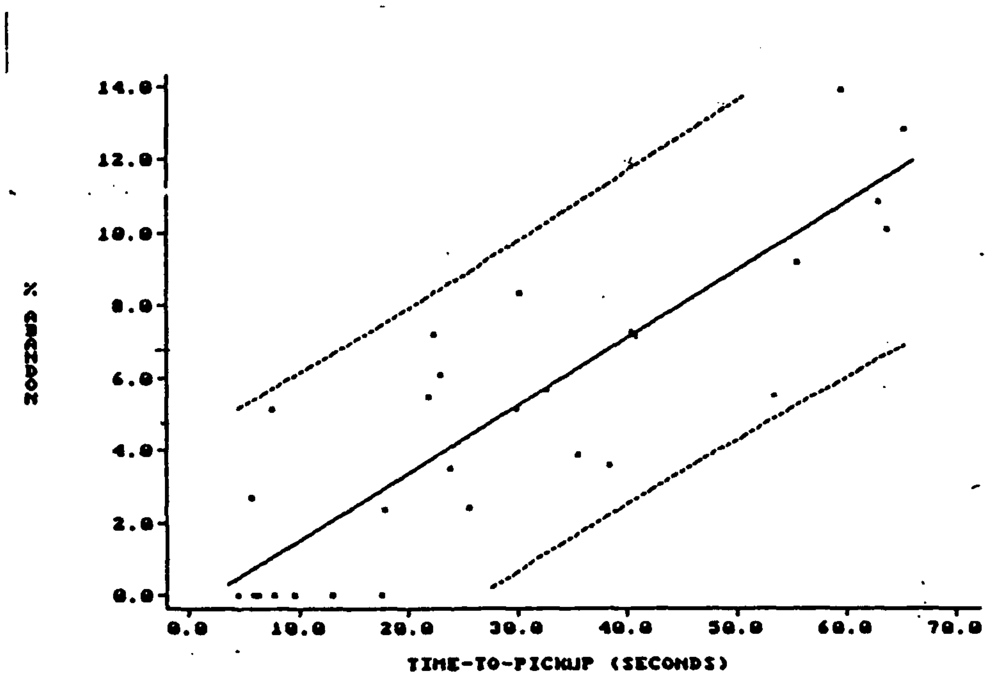

Figure 11 Regression Analysis of Abandoned Hotline Calls

By examining the regression line, a supervisor can quantify the relationship by comparing the rise and run of the line. In the telephone hotline pickup example, the regression line in Figure 11 suggests that if the speed of the pickup is delayed by ten seconds the supervisor can expect the percent of abandoned calls to increase by 2 percent (AT&T 1990). The

analysis now provides a quantitative basis for the supervisor to set realistic goals for improvement.

By establishing a correlation between two variables, there is no guarantee the relationship reflects causation (AT&T 1990). For example, a regression line that correlates an increase in time spent on an examination with an increase in the score of the examination does not imply causation. Informal surveys and personal experiments by both authors suggest that extra time spent on a test does not guarantee a higher score on the test. It is incumbent upon managers to use their knowledge and experience of the process under study to objectively establish the actual cause and effect analysis.

H. CONTROL CHARTS

1. General

Control charts test process measurements against the mean and standard deviation of a theoretical distribution. Control charts generally establish +/-3 standard deviations (about 99.7%) as the control limit. A data point is "out of control" if it lies outside the control limit and represents a special or common cause. While there are several different types of control charts, there are several features common to all control charts (AT&T 1990):

- The points on the chart are process data, either individual data or counts.

- The specific meaning of the points depends on the type of control chart.

- For variable data, the vertical axis represents the unit of measurement of the response. For attribute data the vertical axis is the count, percentage or fraction.

- The horizontal axis represents chronological time.

- The centerline is the mean (average) of all the data plotted on the chart.

- Upper Control Limits (UCL) and Lower Control Limits (LCL) represent 3 standard deviations above and below the centerline.

- Out of Control points are those data points that are outside the control limits. Out of Control points occur due to instability or special causes.

2. Sampling Theory

Sample size greatly affects how accurately a population is represented. While it is generally assumed that data is collected with great care, managers must consider four key factors when considering sample size (AT&T 1990):

- Data must be collected, noted and plotted in chronological order. Notes about known changes or significant events must be included.

- Data must be collected randomly. If there is any screening or adjusting of data, the presentation will be biased. The presentation will not reflect random variation.

- As a general rule, at least twenty points should be on a control chart. While the points mean different things on different control charts, it is generally acknowledged that plotting less than twenty points can result in an inaccurate, misleading chart. Control charts with more than twenty plotted points tend to more accurately portray the process actions.

* The data collection procedure must be consistent. Poor calibration of measuring equipment or collection inconsistencies appear as false changes in the process.

Control charts test the central tendency and variability of a process against those of a theoretical distribution (AT&T 1990). In business terms, control charts allow the manager to:

* Guide business actions and decisions.
* Compare natural statistics of the process to the needs of the customer.
* Distinguish the natural variability of the process from significant changes that need corrective action.
* Maintain continuous fundamental process improvements.

The two basic types of control charts are based on the type of data collected. Variable data control charts involve data that has a measurable characteristic. Underlying assumptions for variable control charts include a normal distribution and the gathering and measuring of detailed information about the process. Attribute control charts are based on data that describes either the presence or absence of a certain characteristic. Attribute control charts require less information and are often the easiest and most convenient control chart to use.

3. Control Charts for Variable Data

The two most common variable control charts are Individual Measurement and Moving Range (X & MR) and Sample

Mean and Range (X-Bar & R). Both charts are based on a normal distribution. If a process measurement is not normally distributed, it may still be used in a Variable Data Control Chart due to the Central Limit Theorem. The Central Limit Theorem states that regardless of the distribution of the universe of the individual measurements, the distribution of the averages (means) of subgroups drawn from those individual measurements will tend toward a normal distribution (AT&T 1990). The larger the subgroup, the closer the approximation to the normal distribution (AT&T 1990). While detailed discussion of statistical theory is not the intention of this thesis, the Central Limit Theorem does permit the use of variable charts on non-normally distributed measurements. This is possible as long as a chart for averages and plots of sample averages are used rather than individual measurements.

a. Variability

The variability of a process is estimated by calculating the standard deviation of individual measurements. A high variability indicates that the individual measurements are spread more evenly throughout a three sigma distribution. A low degree of variability indicates that measurements seldom occur in the two and three sigma regions and are instead concentrated around the mean. In general, larger sample sizes convey smaller spreads (AT&T 1990).

b. *Sampling for Variable Charts*

Sample size is a determining factor in the type of variable control chart used. If individual measurements are normally distributed, a sample size of one may be used (AT&T 1990). If there is suspicion that individual measurements are not normally distributed, then a sample size greater than one should be used. A second determinant for sampling is whether the observations are homogeneous. If they are not homogeneous, then the observations should be broken into rational subgroups whose observations are homogeneous. A characteristic of rationally divided subgroups is that comparison of different subgroups reveals great potential for variability (AT&T 1990). If sample size is greater than one, the number of observations must be determined based on the cost, practicality and feasibility of gathering the data (AT&T 1990). There are many automatic data collection systems that provide continuous data for a given time period. Since the number of occurrences varies, either a randomly selected number of measurements from each time period can be plotted on an X-Bar & R chart or all measurements can be averaged over the given time period and the average considered as an individual measurement using an X & MR chart. Plots of the averages of samples of varying sizes on an X-Bar & R chart will provide biased results.

c. Selecting a Variables Data Control Chart

A logical decision aid for the selection of either X & MR or X-Bar & R charts is provided in Figure 12 (AT&T 1990).

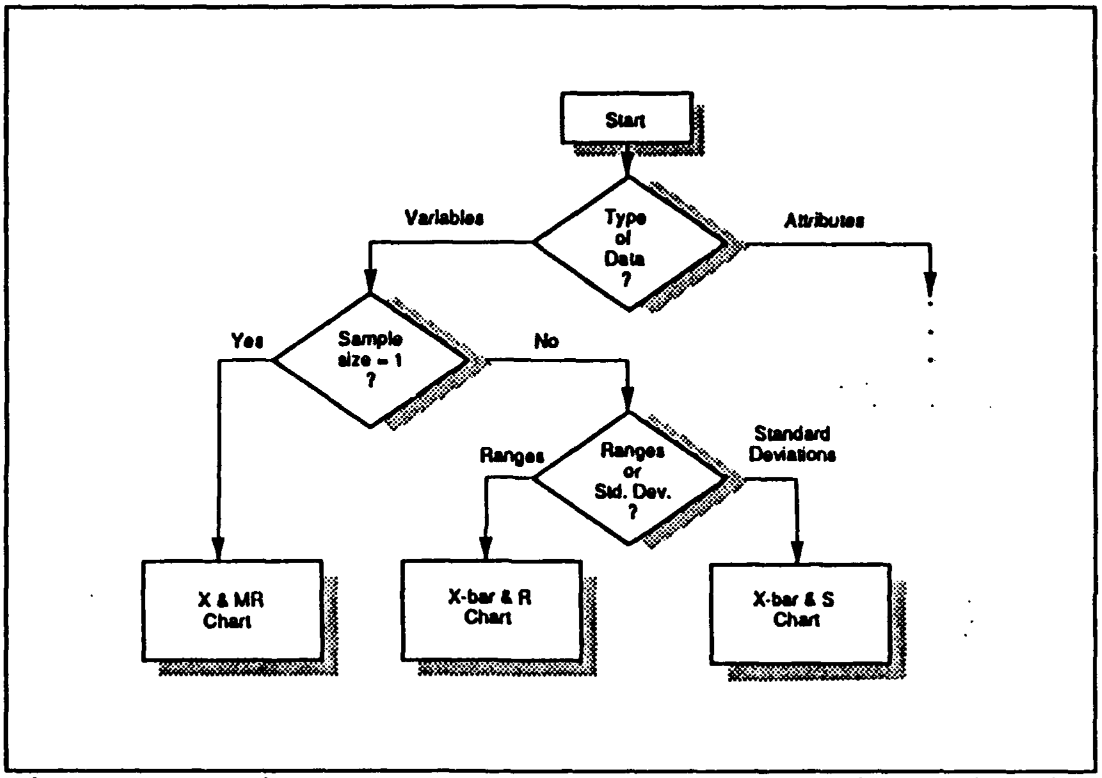

Figure 12 Variable Data Control Chart Selection Criteria

d. X & MR Charts

The X & MR chart plots specific measurements and ranges between consecutive individual measurements. It is useful in many business applications but is relatively insensitive to changes in the process. That is, if there is a shift in the process the chances of a sample falling outside the control limits on an X Chart are much lower than the

chance that the average of a group of four will fall outside the limits on an X-Bar chart (AT&T 1990).

X & MR charts are commonly used in accounting, clerical, and business data involving intervals, costs and fractions. Guidelines for choosing an X & MR chart are (AT&T 1990):

- Constant sample size and rational subgroups are unattainable.
- The cycle time of the process is prohibitively long, resulting in relatively few measurements per time period.
- X-Bar charts are unusable because the information being collected on explanatory variables does not apply if measurements are grouped into samples of more than one. For example, if a data base change entry study grouped measurements of "on-time scores" into samples of four and averaged the measurements within each sample to plot on an X-Bar chart, analysis against explanatory factors such as change type or advance time are impossible because the values are different.
- The individual measurements are expected to mirror the normal distribution if "unnatural" causes are not present.
- Immediate feedback on changes in the process are not needed.
- Attributes charts are impractical because the sample size is large and the occurrence of defects is very low. In this case on an attribute chart, the control limits are so tight that even a small deviation is out of control.

Figure 13 shows an X & MR chart using individual measurement of time to pickup from a telephone hotline (AT&T 1990). Points on the X chart are individual measurements of the response variable, pickup times.

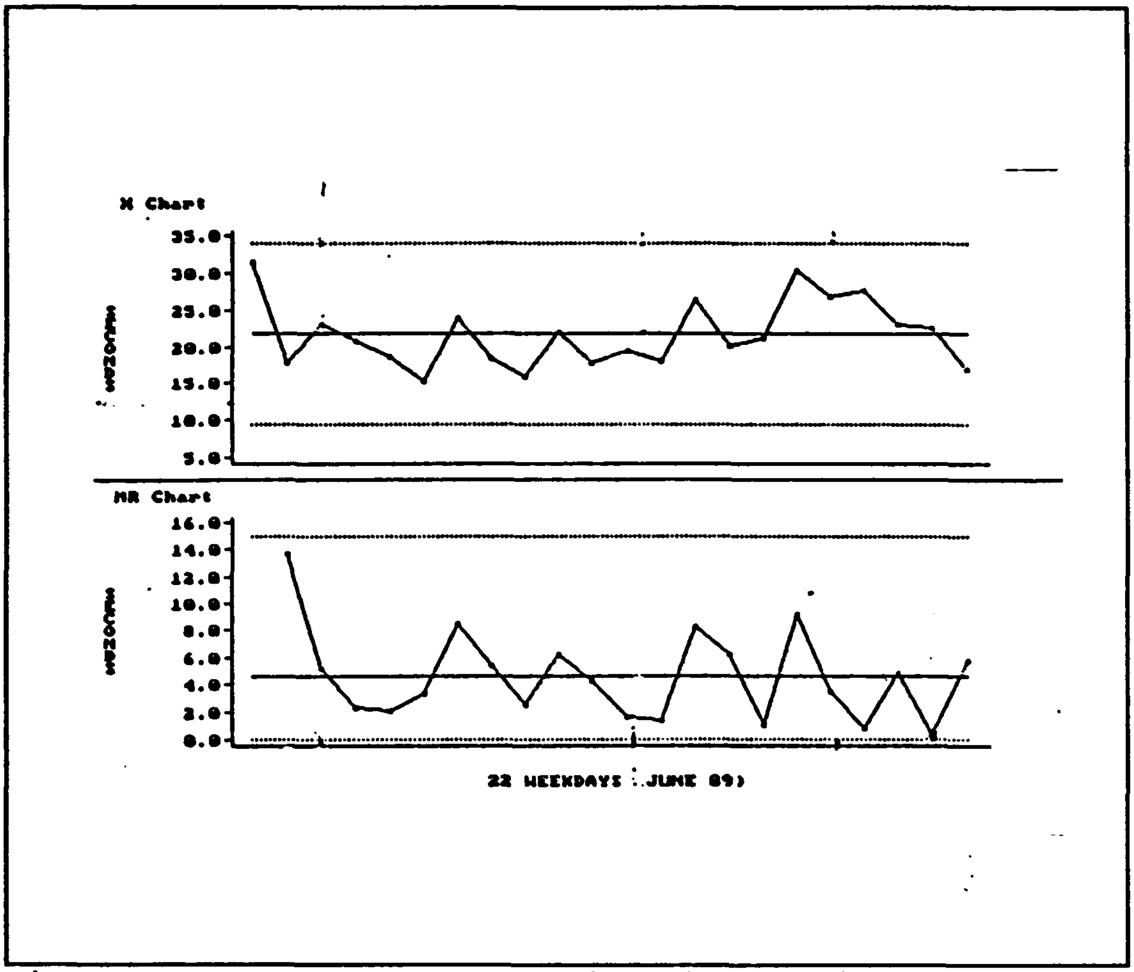

Figure 13 X & MR Chart of Hotline Time to Pickup

Each point on the MR chart is the absolute difference between two consecutive individual measurements. Since the MR charts plot a range defined by two points, there are, by definition, one fewer data points on the MR chart. The Y axis on both charts is the unit of measurement of the response variable. The X axis on both charts is chronological time. The centerline is the average, or mean of the individual measurement on the X chart while it is the mean of the moving ranges on the MR chart.

The control limits of the X chart are calculated from a relationship that uses the average moving range and a relationship between the distribution of MRs and Xs that gives control limits about the same as those of standard deviations (AT&T 1990). Because the limit is derived from the MR chart, the X chart must not be analyzed until the MR chart is under control. An exception to this condition is when the limits are determined by a previous process capability study (AT&T 1990).

e. X-Bar and R Charts

X-Bar and R charts plot sample averages (means) and sample ranges. They can be used under the following conditions (AT&T 1990):

- The creation of rational subgroups is both possible and practical.
- Observations within a rational subgroup tend to have the same values as those of explanatory values.
- It is possible to maintain constant sample size with all subgroups having the same number of observations.
- There is uncertainty that the measurements will mirror the normal distribution. According to the central limit theorem however, the distribution of the rational subgroups will be normal.

Figure 14 shows an X-Bar and R chart describing an employee change notification process (AT&T 1990). The points on the X-Bar chart are the averages (means) of the individual measurements of a sample or subgroup. The points on the R

chart are the ranges between the highest and lowest values of each subgroup.

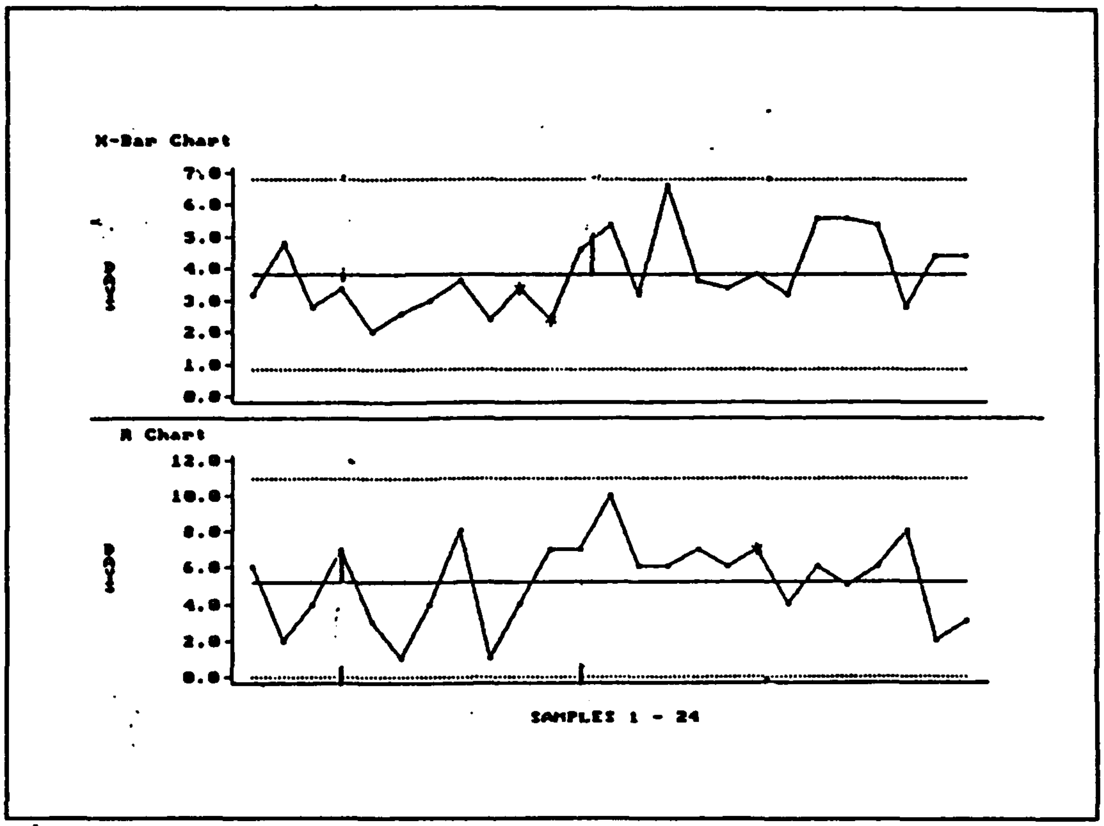

Figure 14 X-Bar and R Chart of Employee Change Notification

The Y axis on both charts are the units ofmeasurement of the response variable and the X axis is time. The centerline of the X-Bar chart is the mean of the X-Bars known as X-Bar-Bar. The mean of the ranges, R-Bar is displayed as the centerline of the R chart.

Control limits for the X-Bar chart again rely on a derived statistical relationship between Rs and X-bars that incorporates a function of the number of observations in the sample (Gitlow 1990). As in the X and MR charts, the X-Bar

chart should not be interpreted until the R chart is under statistical control.

The control limits for the R chart are developed by a statistical relationship based on the expected distribution of the Rs and a function of the number of observations in the sample (Gitlow 1989).

f. X-Bar and s Charts

X-Bar and s charts are quite similar to X-Bar and R charts. Both charts provide the same kind of information but the X-Bar and s chart is best used when subgroups consist of 10 or more observations (Gitlow 1989). X-Bar and s charts are particularly well suited to highly repetitive production tasks that are monitored intensely. Consequently, this type of chart has limited application for the telecommunication system manager.

4. Attributes Control Charts

a. General

Attributes control charts analyze properties that either do or do not exist. For example, on time/late, right/wrong and all accurate/with errors are attributes of a process. While there is a comparative lack of information about the process compared to variables charts, there are several important benefits of attributes control charts (AT&T 1990):

- Not all characteristics can or should be measured. For example no one really cares which field position of a Unit Identification Code (UIC) is in error on a naval message. The important characteristic,or attribute, is that the UIC is in error. Similarly, the manager must consider that he will not know how many digit positions in that UIC.

- Variable data may be impractical or too costly to collect.

- If a process is running smoothly, variables charts can represent an overkill of analysis. Attributes charts can save time and reduce complexity for mature, controlled processes.

If a data collection process is already in place, attributes charts may provide a very cost effective use of the data collection process.

Attributes charts can be broken into two general groups. In the first case a manager may want to look at the number of defects or failures to meet a specific requirement. Or, a manager may be interested in defective products regardless of whether each defective product has one or more defectives. Attributes charts are further divided into subgroups that depend on whether constant sample sizes exist. Figure 15 describes the criteria for appropriate chart selection (AT&T 1990). In this paper, np and c charts for constant sample sizes will not be discussed as they can be easily interpreted with an understanding of "P" and "U" charts which are discussed below.

b. Sampling for Attributes Control Charts

In the context of attributes data, a sample is made up of the number of units inspected to plot each po. t on

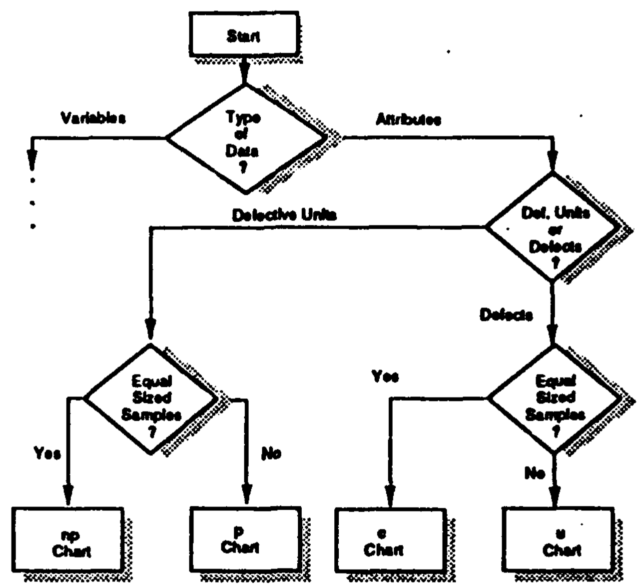

Figure 15 Attribute Data Control Chart Selection

the control chart. Although the sample size for variables data must be constant, the sample size for attributes data can vary (AT&T 1990). While it is convenient that the sample size for attributes charts can vary, there is a requirement to collect more data. For attributes charts, the sample size must be large enough so that there is a good chance that a defect will be discovered. Ignoring the requirement for large amounts of data will result in charts that provide misleading and sometimes sensational images. A basic rule of thumb for recommended sample size is that there must be enough inspection so that at least one defect or defective is discovered at least 90% of the time (AT&T 1990).

c. P-Charts

P-Charts plot the percent or fraction rejected or percent or fraction of defective units. P-Charts compare the number of non-conforming items to the total number of items inspected. P-charts are useful under the following conditions (AT&T 1990):

- Each of the units produced has about the same chance of being defective.
- The number of items in the sample varies.
- The manager wants to know what the chances are that a unit will be defective.

Figure 16 shows a P-Chart of the percentage of abandoned calls from the telephone hotline example (AT&T 1990). Remarkable features of the chart include the centerline and the control limits. The centerline represents the average fraction defective calculated by dividing the total number detectives in all samples by the number of units in all samples. The control limits are plus or minus three standard deviations of each sample from the mean based on a binomial distribution. A binomial distribution yields the probability of failure for the number of units inspected.

d. U-Charts

When it is preferable to count defects rather than defectives, a U-Chart is useful. For example, a manager

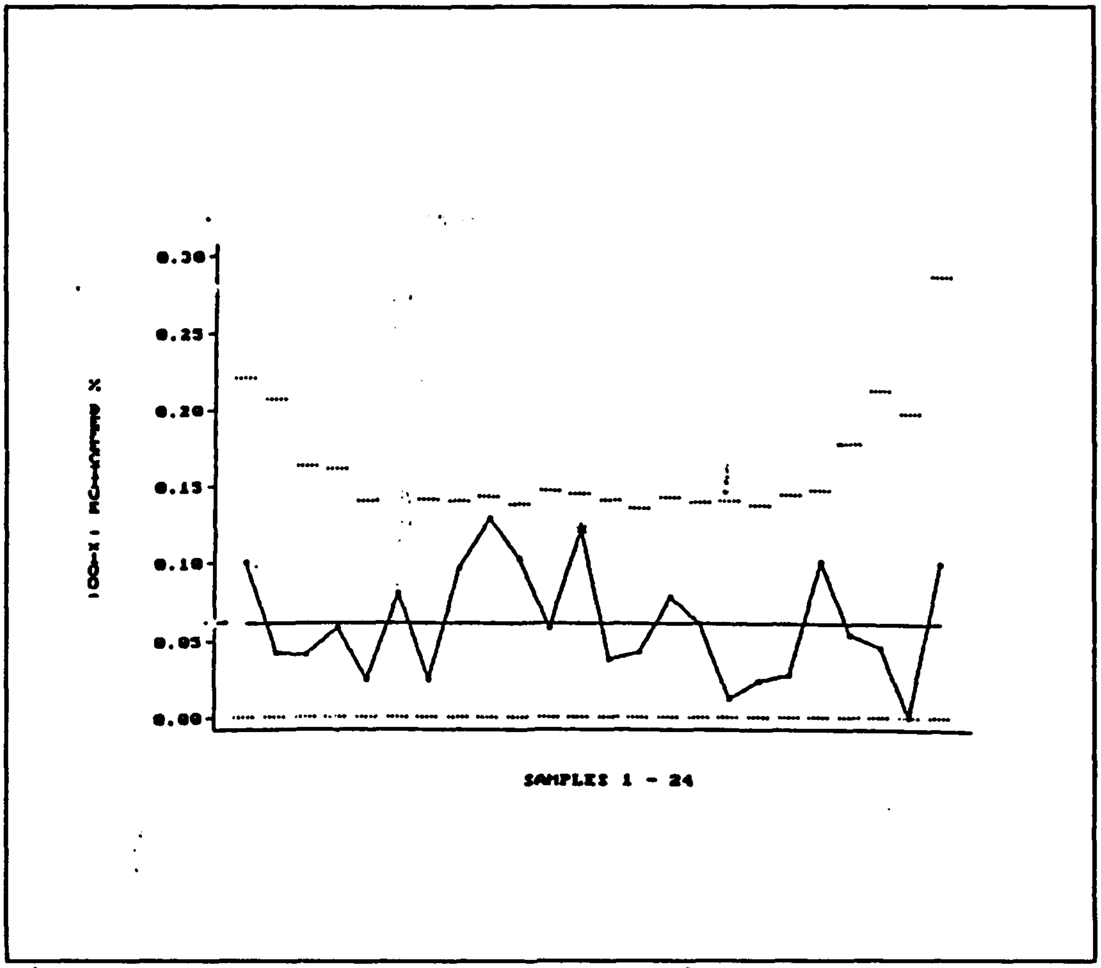

Figure 16 P Chart of Abandoned Hotline Calls

may want to know how many and what types of mistakes are made for each naval message. Defect tracking charts are based on a Poisson distribution which stipulates that the sample size should be such that the opportunity for a defect to occur is very large and the actual chances of an occurrence of a defect is very small. Processes such as database management are well suited to U-charts.

Figure 17 is a U-Chart of a defects per page of a data base (AT&T 1990). Each point is a ratio of defects per

unit. The Y axis is the number of defects per unit. The centerline is the average number of defects per unit calculated by dividing the total number of defects in all samples by the number of units in all samples. Finally, the control limits are based on the deviation of each U from the mean based on a Poisson distribution. Poisson distributions consider the possibility of multiple non conformities on each item.

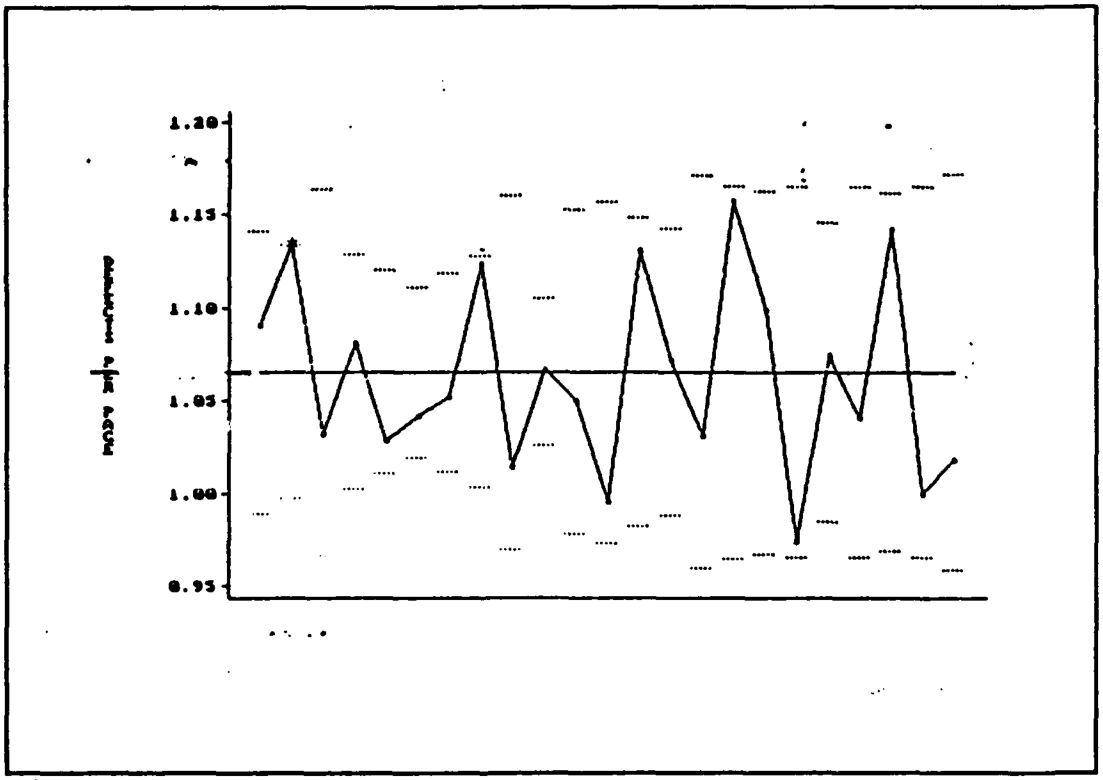

Figure 17 Defects per page- U Chart

5. Improving Quality with Control Charts

Interpretation of control charts is considered by many to be an art form. While interpretations of control charts are ultimately left to senior statisticians, it is both

educational and informative for the manager to be familiar with chart interpretation.

Selecting the right control chart for a set of circumstances can be difficult. In fact, using the wrong chart usually results in process tampering (Trietsch 1992). Decisions about which type of control chart to use should be made by very experienced statisticians. Those that succumb to the great temptation to "hack" by experimenting with different charts will do tremendous damage to the process (Deming 1986). Figure 18 summarizes the decision criteria for control chart type selection (AT&T 1990).

Total quality management emphasizes that a process must be brought under control before it can be improved. Once a process is under control, continuous improvements and controls refine the process indefinitely. The process of quality implementation can be broken into three distinct processes (AT&T 1990):

- Process Capability Study
- Process Control
- Process Improvement

In the process capability study, control charts detect, quantify and eliminate causes of variability. Elimination of variability due to special causes brings the process under statistical control.

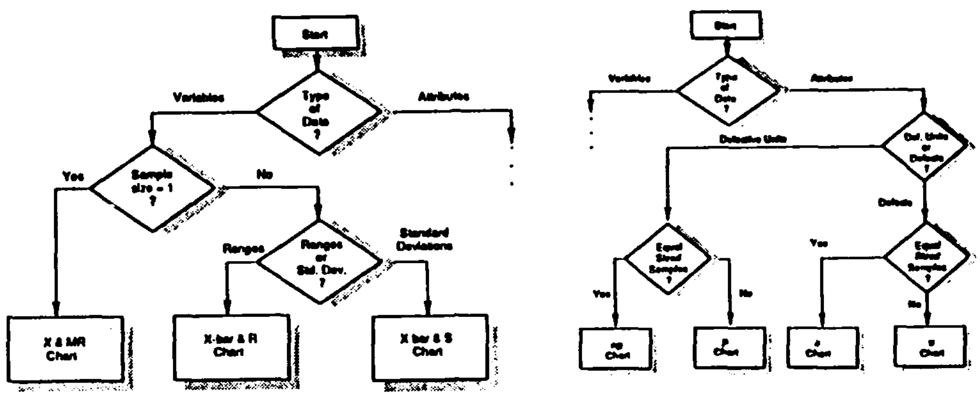

Figure 18 Control Chart Decision Tree

Process improvement is a logical introduction of fundamental changes to the process that improve the level of performance. As new levels of performance are realized and controlled, still newer levels are introduced.

Finally, control charts monitor the new limits achieved through the continuous improvement process. Figure 19 is a summary of the refinement of a generic process using control charts to increase quality (AT&T 1990).

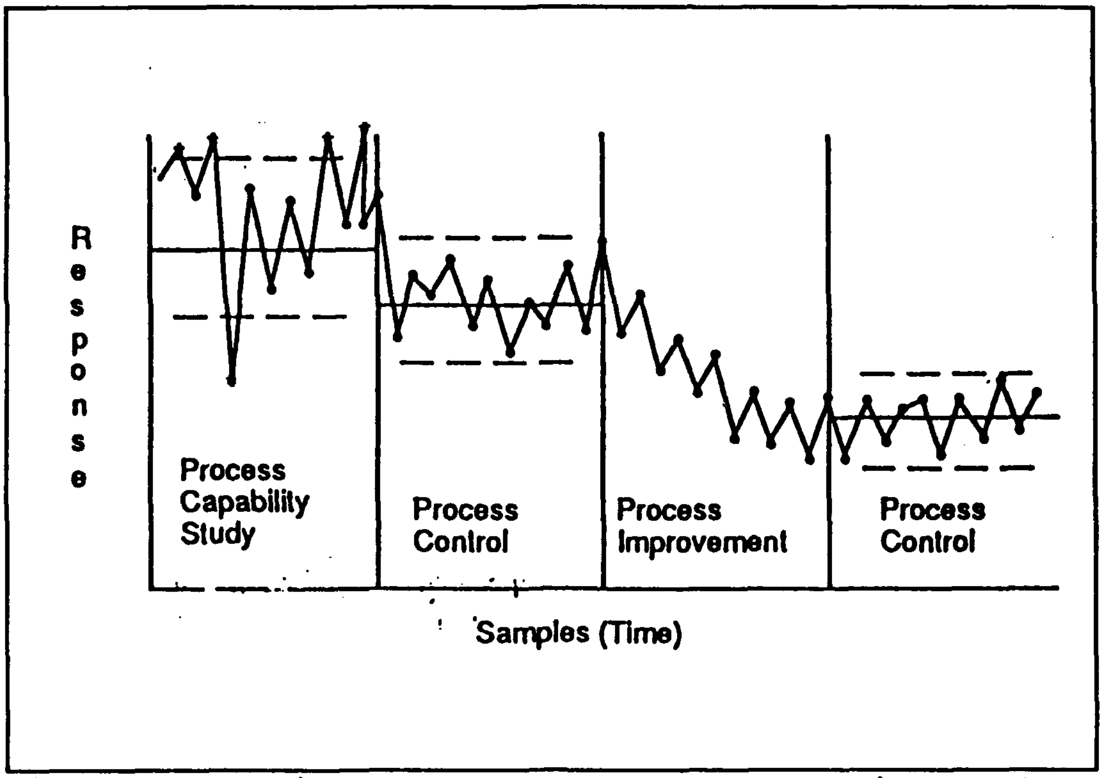

Figure 19 Continuous Process Improvement with Control Charts

IV. ADVANCED QUALITY TOOLS

A. GENERAL

The purpose of this chapter is to acquaint the telecommunications manager with more advanced methods of SPC. While direct application of these tools in a telecommunications environment may not be readily apparent, several concepts addressed within the framework of the advanced tools discussed can be of assistance in gaining a better understanding of SPCs and their capabilities.

B. ANALYSIS OF MEANS

While Analysis of Means (ANOM) is a statistically difficult tool to describe, its results are both easy to understand and useful to analyze. ANOM graphically compares categories of variables and highlights statisitically significant differences. Unlike boxplots, ANOM can be used with either variables or response data (AT&T 1990). Figure 20 continues with the data base change processing time example (AT&T 1990). Key features of this technique include (AT&T 1990):

- The centerline is the overall process mean.
- Each point represents the mean of a category. The line connecting the means is simply a visual cue.

* Decision lines are similar to control limits that use standard deviation to indicate a point above or below which it is improbable that a point will occur. Decision lines are influenced by sample size of the individual category and sample sizes of the other categories.

* Flags, indicated by an asterisk, indicate a statistically significant difference in performance. In the change entry example, the manager sees the hourly and resign categories perform significantly better than the overall mean. He could then investigate the causes that produced these improvements and implement those changes to the entire process.

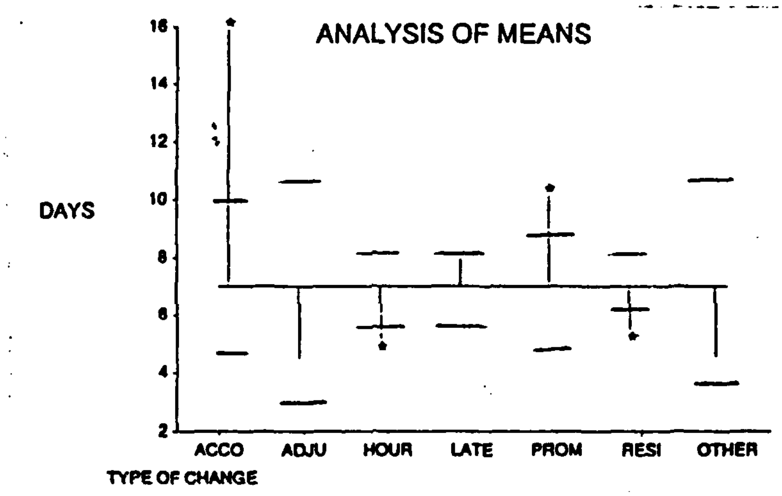

Figure 20 Analysis of Means of Changing Processing Time

ANOM is critically dependent on computer processing. Numerous software packages exist that perform ANOM.

C. DESIGN OF EXPERIMENTS AND ANALYSIS OF VARIANCE

1. General

Experiments are conducted and analyzed when historical data is unable to provide the manager with sufficient information. Situations requiring experimentation include (FP&L 1989):

- The historical data is of questionable origin.
- A significant process change invalidates the historical data.
- The process has no historical data.

In these cases, experiments designed on a statistical basis are very useful in improving the quality of a good or service. The statistical analysis of experiments is called Analysis of Variance (ANOVA).

2. Design of Experiments

Consideration must be given to specific inputs (factors) to the process that must be controlled, manipulated or allowed to vary at random. Factors usually have several levels which are used to set various values in the experiment. For example, an analysis of an optical print scanner may have several levels of scanning resolution or sampling.

The design of the experiment must abide by three concepts known collectively as "max-min-con" (FP&L 1989):

- **Maximize** the factor of interest.

* **Minimize** the variation caused by other factors that can affect the output but do not have a major impact.

* **Control** the variation caused by factors which do have a major impact on the output but are not of interest in the experiment.

It is important to note that these constraints provide results that are valid only for the conditions of the experiment. Consequently, interpretation and projection beyond these conditions is unwarranted.

The experiment can be designed with or without repetition. In a **factorial** design **without repetition**, each level of each factor is combined with each level of every other factor to provide a test run for each combination. In a **factorial** design **with repetition**, each experiment is conducted several times to get an estimate of the mean and standard deviation of the experiment distribution represented by each combination of factor levels.

The optical scanner example will be used to illustrate these experiment techniques. The scanner is one of several factors that affect message accuracy. A fishbone diagram portrays other key factors in the accuracy of messages as shown in Figure 21.

Other inputs to the system that cause unwanted, but small, variation are ignored. In the scanner example, the sampling algorithm of a digital scanner may introduce a minimal error in the quality of the scanned image.

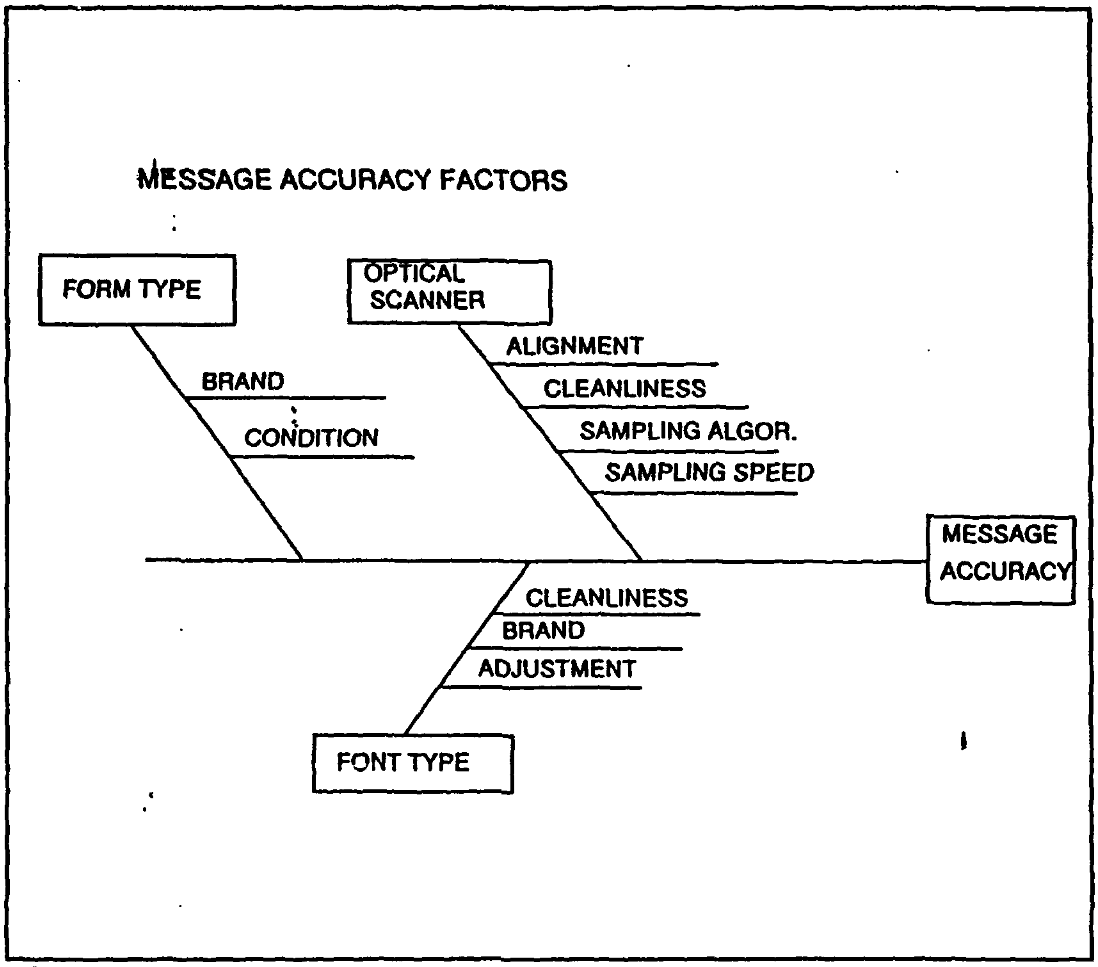

Figure 21 Message Accuracy Factors

The second factor considered in this example is printer font brand. For the purpose of this discussion, assume that the two suppliers of the printing devices intrepreted the specifications differently according to height, width and thickness of optically scanned characters. If each scanner setting is tested against each type of printer, the experiment would appear as a **full factorial without repetition** as shown in Figure 22.

FULL FACTORIAL WITHOUT REPETITION

PRINTER FONT BRAND	SCANNER SPEED		
	LOW	MEDIUM	HIGH
BRAND A	1	2	3
BRAND B	4	5	6

Figure 22 Scanner Experiment Without Repetition

If the printing device is considered as a third factor with four levels, the number of experiments increases to 24;(3X2X4). Management must consider the potential benefits of more detailed information against the cost of each additional experiment (FP&L 1989).

If means and standard deviations are desired, the experiment is set up as a **full factorial with repetition.** As illustrated in Figure 23, the number of experiments increases

from the previous experiment by a factor of six if three experiments are performed for each combination.

FULL FACTORIAL WITH REPITITION

(ORDER OF EXPERIMENT TRIALS DETERMINED BY RANDOM NUMBER GENERATOR)

PRINTER FONT BRAND	SCANNER SPEED		
	LOW	MEDIUM	HIGH
BRAND A	3,16,18	9,11,8	12,5,1
BRAND B	14,6,10	17,4,13	7,2,15

Figure 23 Scanner Experiment With Repetition

While the increased expense of full factorial experiments with repetition is obvious, the benefits of the multiple experiments may not be. Repetition can reveal certain combinations of factors that react significantly different from the overall experiment (FP&L 1989). For example, Type A forms may be better for overall print accuracy but Type B forms at the more efficient "Low" scanner setting may be the most accurate specific combination. Known as "interaction," these specific combinations can be extremely useful if identified and used to their advantage.

The experimental order must be arranged to minimize the effects of uncontrolled variables. This is usually accomplished by randomizing the order of the trials. For the scanner example, a random sequence of experiments is shown in Figure 24.

FULL FACTORIAL WITH REPETITION

PRINTER FONT BRAND	SCANNER SPEED		
	LOW	MEDIUM	HIGH
BRAND A	1,2,3	4,5,6	7,8,9
BRAND B	10,11,12	13,14,15	16,17,18

Figure 24 Sequence of Experiments

3. Analysis of Variance (ANOVA)

ANOVA is an analysis that decomposes the total variance in a data set into pieces which can be attributed to various factors (FP&L 1989). If the presence of a given

factor level is the primary source of variation in the data, it is shown that the factor has a significant impact on the process. ANOVA can be used to analyze properly gathered historical data but is most often used in a designed experiment.

In One Way ANOVA, one source of variation is attributed to changing the level of a factor. The second source of variation is error from random variation and other non-isolated factors.

Two Way ANOVA identifies three sources of variation (FP&L 1989):

- The level of the first factor
- The level of the second factor
- Error and non-isolated factors

In the optical scanner example, a determination could be made that both the form type and scanner setting were significant and that the best combination was the type "A" form with the "High" scanner setting.

Interaction effects of levels of the factors are revealed by Two Way ANOVA with repetition. The interaction effects are isolated as their own source of variation (FP&L 1989). ANOVA requires a relatively sophisticated knowledge of two concepts not covered here: hypothesis testing and internal estimation. While ANOVA should not be used without

a qualififed statistician, it is important to note the vast potential for telecommunication application of this technique.

D. WEIBULL DISTRIBUTION

Weibull analysis investigates the failure distribution of equipment. Using a computer system as an example, the reliability of the system can be broken into categories depending on the type of failure. Depending on the accumulated operating time, the failure processes affecting a population of equipment may be different. These failure processes, in turn, may be described by different probability distributions. If the number of failures the computer system experiences are plotted on a histogram, smoothed into a curve and stratified by failure process, a Weibull distribution of failure appears as in Figure 25. The three failure processes are described in Figure 26 in terms of causes and corrective measures (FP&L 1990).

If the manager wishes to improve the reliability of the computer system, he must focus on the types of failure experienced by the system at specific times. Obviously, preventive maintenance does not eliminate the inefficiencies resulting from special cause variation. Similarly, if preventive maintenance is performed during the burn-in stage, the reliability might be decreased because a seasoned computer is less likely to fail than a new one.

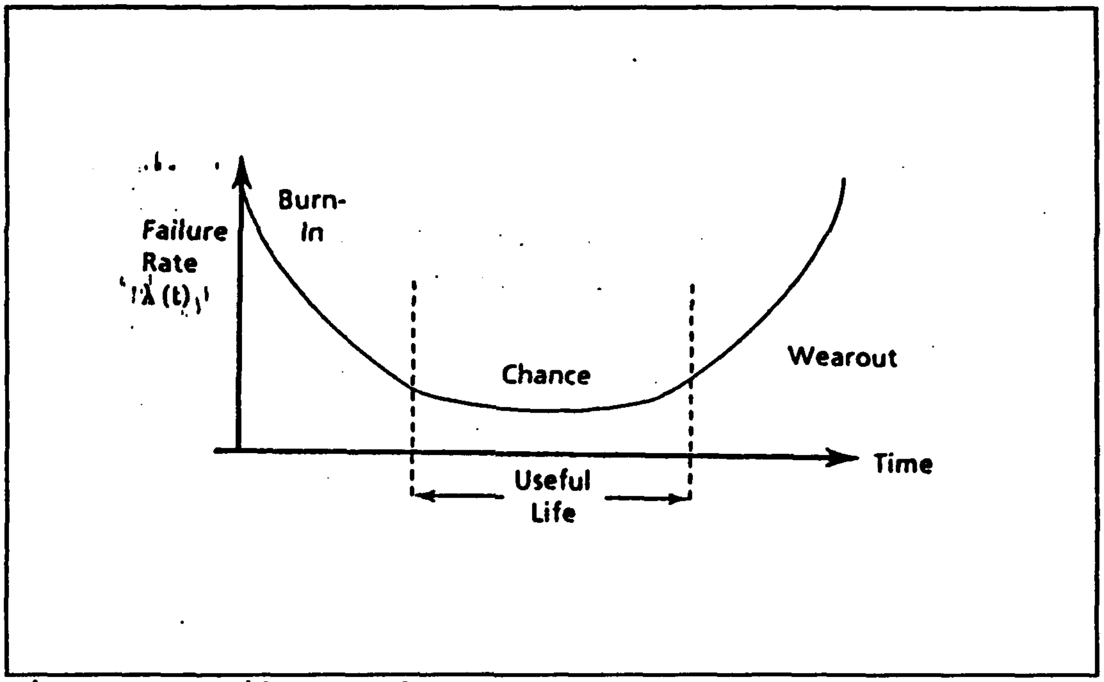

Figure 25 Failure Modes

Preventive maintenance is intended to prolong the useful life of a product or piece of equipment. Effective scheduling of preventive maintenance for computer hardware and software through Weibull analysis, for example, greatly increases the chances of uninterrupted, failure-free operation.

The Weibull distribution has many different applications-- in both industrial and service settings:

- Prediction of the number of failures expected in a population in a given time period.
- Prediction of the number of spare parts needed in a given time period.
- Prediction of the life cycle costs or yearly maintenance costs for budget analysis.
- Length of test or operation time required to determine if a system change has either eliminated or reduced the probability of a certain failure mode.

FAILURE TYPE	CAUSES	CORRECTIVE MEASURE
BURN-IN	MANUFACTURING QC	IMP. VQIP
	DESIGN PROBLEM	REDESIGN
	MAINT. ERROR	TRAINING, PROCEDURES
CHANCE	ENVIRONMENTAL STRESS ITEM STRENGTH	REDESIGN, DERATE, PROTECT AGAINST ENVIRON.
WEAROUT	PHYSICAL WEAR, ITEM DETERIORATION	REPLACE, REPAIR, REDESIGN (LONGER LASTING MATERIAL)

Figure 26 Failure Causes and Corrective Measures

The horizontal axis of time can be changed to characteristics such as voltage, pressure, time to complete a process, or quality. The costs of quality can be described using a Weibull distribution and are discussed later in this chapter.

E. TAGUCHI METHODS

1. General

Taguchi methods are designed to reduce the variance of a process, set economical tolerances and improve product design (Taguchi and Clausing 1990). They deal with two of the three types of defects in a product: products that are out of

tolerance and bad designs. The third type of defect, mistakes, are remedied by Poka-Yoke methods that are introduced later in this chapter.

2. Off-line Quality Design

Products that are out of tolerance due to bad designs can be improved by off-line quality design. The basic premise is that the "robustness of products is more a function of good design than on-line control, however stringent, of manufacturing processes" (Taguchi and Clausing 1990).

The first key principle of off-line quality design has to do with consistency of performance. Taguchi emphasizes a target-oriented continuous effort to produce a product with minimal variation from a goal. The concept is in contrast to the well known and used specification limits. A product whose every component is within specification may still fail the consumer when all the seemingly trivial variations within the specification limits stack up to render the product defective (Taguchi and Clausing 1990). One of the more famous examples of this situation occurred when Ford compared its transmissions with those made by Mazda for the same automobile. Ford found that the rework, scrap, warranty nad production costs for Ford transmissions were significantly higher than Mazda's. Internal investigations of the transmissions revealed that while all transmissions were within specification limits, the Mazda transmissions

demonstrated no variability whatsoever from target values. The Mazda transmissions were built on the assumption that product robustness begins by meeting exact targets consistently (Taguchi and Clausig 1990).

The second principle states that overall losses are actually quality loss plus factory loss. Factory losses occur during design and production. Quality losses are the losses that occur after the product is shipped. Quality losses usually increase geometrically (Taguchi and Clausig 1990). The more the manufacturer deviates from his targets, the greater his losses. The Taguchi Loss Function (TLF) roughly indicates that the loss increases as the square of each individual deviation times the cost to remedy that the manager might use to get the process back on target (Taguchi and Clausing 1990). While actual data will not be completely loyal to the equation, the TLF translates the notion of deviation into simple cost estimates. The financial implications of this relationship reveal that customer dissatisfaction grows with deviation, and dissatisfaction is then related to financial loss by the TLF (Roslund 1989).

Taguchi methods set targets based on a concept known as the "signal to noise" ratio. The signal is what the product is supposed to deliver. Noise is the interference that degrades the performance of the signal. Robustness can then be defined as a product with a high signal to noise ratio (Taguchi and Clausing 1990). In a sense, the signal to noise

ratio is the measure of the faithfulness to the intention of the overall design. In consumer terms, a high signal to noise ratio would be a product that continues to perform well under less than optimal conditions.

The culmination of Taguchi methods is a Systems Verification Test (SVT). A prototype is built that incorporates the minimized signal to noise ratio to optimize design values. Any deviation from a perfect signal is then analyzed in terms of the QLF (Taguchi and Clausing 1990). Thus, before a product goes into full operation, the average square of the deviations from the targets are minimized (Taguchi and Clausing 1990). In the final steps, best values for each parameter are established based on total production costs plus quality costs. Once production is underway, interventions are determined by their impact on the QLF.

F. POKA-YOKE

Mistakes require process improvements called Poka Yoke or mistake proofing. Shiego Shingo developed Poka Yoke methods to incorporate 100% inspection at the source of quality problems through low cost, in-process quality control mechanisms and routines (Dyers 1990). Natural and normal lapses in the attention of workers must be compensated for by the system. Poka Yoke attempts to build the function of a checklist into an operation. For example, if a regularly received naval message has an Address Indicator Group (AIG)

that includes nine addressees, bins for each message copy could be arranged in a logical sequence that prevents the operator from missing an addressee.

There are four underlying principles of Poka Yoke that apply in industrial as well as service implementations (Dyer 1990):

- Control upstream, as close to the source of the potential defect as possible.
- Establish controls in relation to the severity of the problem.
- Strive for the simplest, most efficient and most economical intervention.
- Do not delay improvement by over-analyzing.

These concepts can be practically integrated with "intelligent machines" that stop automatically when processing is completed or when an abnormality occurs. Processing operations are particularly well suited to Poka Yoke. Obvious applications in the telecommunications field include message processing and data base management.

G. THE QUALITY COST MODEL

1. General

While quality tools such as Taguchi methods attempt to put a dollar value on the variation in a product or service, decisions about the level of quality in a product frequently refer to relationships derived from quality cost models.

These models are based on the relationship among prevention, appraisal and failure costs. The cost model discussed here was developed in the accounting field and as a result deals with more tangible, measureable aspects of quality. The total quality movement increased the importance of quality and has forced the modification of the original cost models to include quality variables that in the past had been neglected. While the cost model is not specifically a management tool, it can provide valuable insights into the relationships among the various types of quality costs and show the economic significance of quality factors. Herculean quality efforts such as Motorola's "Six Sigma" program raise an important quality cost question. Can we spend too much on quality? The proper analysis and control of these quality costs presents a critical problem for management.

2. Component Quality Costs

The major categories of quality costs are prevention, appraisal and failure (Heagy 1991). Each quality cost has a direct bearing on the amount that should be spent on others. Each cost category is described below:

a. Prevention Costs

Prevention costs are those taken to investigate, prevent, or reduce defects and failures (BSI 1981). They are preemptive costs, an attempt to ensure quality before the actual manufacture of the product. It is an attempt to "do it

right the first time" (Port 1987). Most current trends in total quality, notably Taguchi methods, advocate the importance of maximizing the effort in this area (Port 1987).

b. Appraisal Costs

Appraisal costs are the cost of assessing the quality achieved (BSI 1981). These are the traditional costs associated with quality control including costs of inspection before the product leaves the plant. Despite high efficiencies of appraisal techniques, it does not eliminate the need to replace or rework defective products nor does it eliminate the causes of defective products.

c. Failure Costs

Failure costs are costs that are the result of insufficient or ineffective spending in the prevention and appraisal cost categories and are broken down into two groups:

(1) Internal Failure Costs. Internal failure costs are the costs arising within the organization for failure to achieve quality specified before the transfer of ownership to the customer (BSI 1981). These costs are comprised mainly of costs incurred for the rework of defective items discovered during appraisal (Heagy 1991).

(2) External Failure Costs. External failure costs are the costs arising outside the organization of the failure to achieve quality specified after the transfer of ownership to the customer (BSI 1981). These costs include

warranty repairs and replacements, returns and allowances due to quality problems and the costs of lost sales due to a bad quality reputation among customers (Heagy 1991).

A summary of prevention, appraisal, and failure costs is included in Figure 27 (Heagy 1991).

3. Opportunity Costs of Lost Sales/Usage

The quality cost model presented here considers several key economic concepts as they relate to the cost of quality. The cost of lost sales/usage due to a poor quality reputation is a multi-faceted issue that encompasses several economic considerations. Considered as external failure costs in the model, lost sales/usage is difficult to measure but is a critical factor in overall quality cost determination. Key economic factors affecting the quality costs are presented below.

a. *Elasticity of Quality Demand*

Elasticity of quality demand directly relates the demand for a product to certain aspects of the quality of the product. If a product's demand is inelastic, the demand should stay somewhat constant as quality varies. If a product's demand is elastic, demand for the product will fluctuate in direct relation to its quality. An example of an elastic quality good is an AUTODIN naval message. If the quality of the message drops, customers are apt to switch to a form of communication that provides the quality of service desired.

Components of Quality Costs

Prevention Costs

*Product research and design
*Quality engineering
*Quality Circles
*Quality education and training
*Supervise prevention activities
*Pilot studies
*System development and implement
*Process controls
*Technical support to vendors
*Auditing effectiveness of quality system

Internal Failure Costs

*Net cost of scrap
*Net cost of spoilage
*Disposal of defective product
*Rework labor and overhead
*Reinspection of reworked product
*Retest of reworked product
*Downtime due to quality problems
*Net opportunity cost of "seconds"
*Data reentered due to input errors
*Defect cause analysis and investigation
*Revision of in-house computer programs due to software error
*Adjusting entries necessitated by quality problems

Appraisal Costs

*Supplies used in testing and inspection
*Test and inspection of incoming materials
*Component inspection and testing
*Review of sales orders for accuracy
*In-process inspections
*Final product inspection at customer site prior to final release of product
*Reliability testing
*Supervision of appraisal activity
*Plant utilities in inspection area
*Depreciation of test equipment
*Internal audits of inventory

External Failure Costs

*Cost of responding to customer complaints
*Investigation of customer claims on warranty
*Warranty repairs and replacements
*Out of warranty repairs
*Product recalls
*Product reliability
*Returns and allowances due to quality problems
*Opportunity cost of lost sales due to bad quality reputation

Figure 27 Summary of Quality Costs

b. *Suitable Substitutes*

Suitable substitutes are products that provide a like service. It is the presence of these substitutes that allows the consumer to maintain flexibility in their decisions concerning services. In the area of naval telecommunications, suitable substitutes can include: facsimiles, satellite communications, HF/VHF/UHF radio transmission, AUTODIN messages, NAVGRAMs, telephones, and computer networks. Though these modes represent unique forms of communication with specific purposes, they can be substituted by the consumer. A classic example is a consumer sending a message via AUTODIN rather than NAVGRAM because of a perceived lack of quality in the handling of the NAVGRAM messages. A similar example is the ashore use of out-WATS telephone services rather than the AUTOVON system because of a perception of poor quality service provided by AUTOVON. The difference in the costs of these two types of telephone services are significant and suggest that substitution is a very costly factor within the naval communications organization. The recognition and growth of quality as a factor in consumer preference has resulted in increased competition among similar communication services.

c. *Customer Loyalty*

Despite the lure of better quality products, some consumers will maintain allegiance to a single source for a product despite low quality.

d. Risk Aversion

The discussion until now has assumed that the optimum level of quality relies solely on incremental cost measurements. There are many industries that consider 100% error free performance as a minimum. Examples of this include parts of our space program that are crucial to the success of the larger mission such as deep space communication systems or telescope lenses (Heagy 1991). As quality continues to grow in importance to customers, more organizations will strive for completely error free performance. Besides linkage to the success of a much larger program, organizations can develop a strong and loyal customer base that often makes repeat purchases or relationships with a minimum of additional expenditure.

4. The Quality Cost Model

The quality cost model is shown in Figure 28. This family of curves is based on a Weibull distribution and depicts the relationship between the components of quality costs. For simplicity, prevention and appraisal costs are combined on one curve to show their effect on failure rate.

The graph describes both the quality costs and failure costs in terms of cost (vertical axis) and percentage of quality goods (horizontal axis).

The curves depict the amount of expenditures on appraisal and prevention costs as they relate to the level of

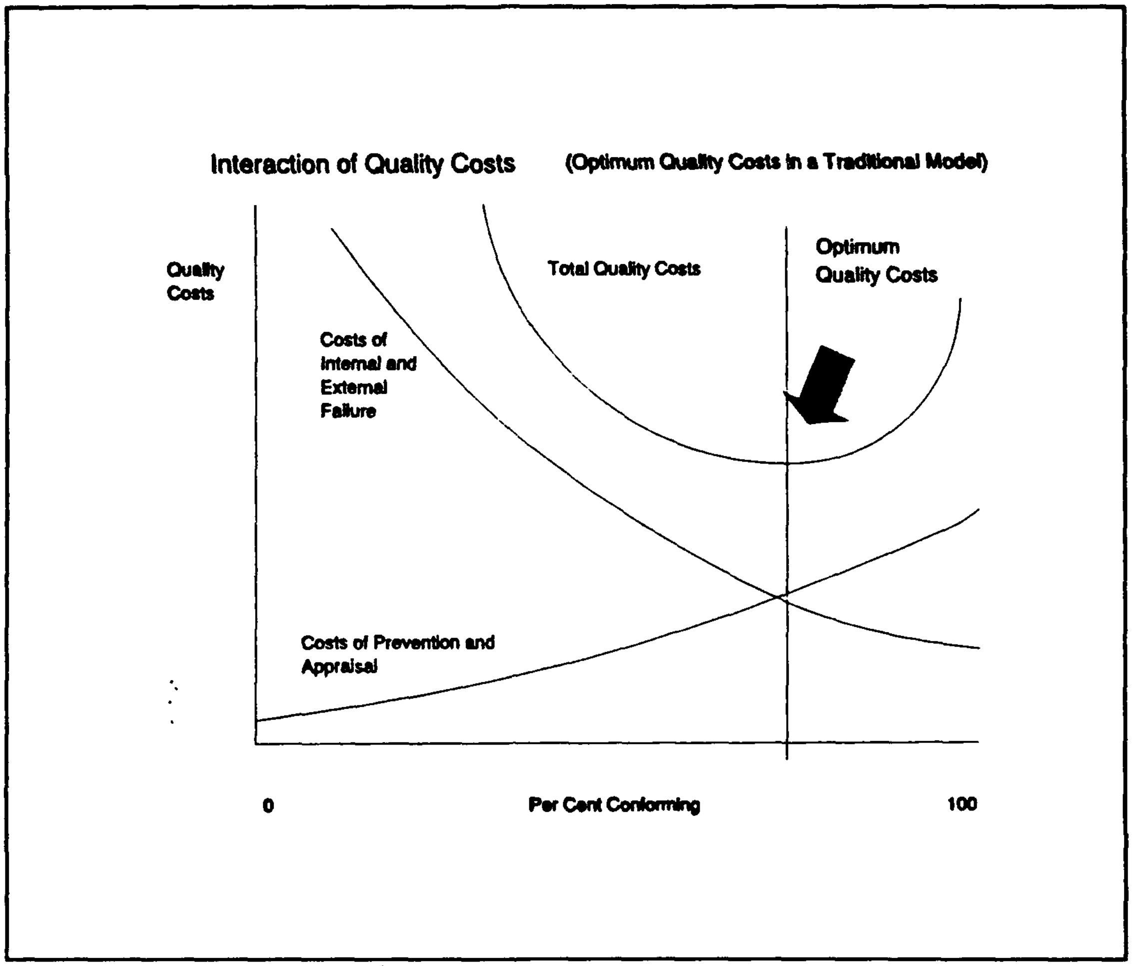

Figure 28 The Quality Cost Model

quality assurance. The model also shows the inverse relationship between the level of quality costs and failure costs.

Also depicted in the model is the total quality cost curve. This curve is the sum of the prevention plus appraisal costs and failure costs. It is this curve that is of particular use to the manager as it shows the optimal amount to spend on quality. This point is the minimum point on the total quality cost curve. Any movement from this point

results in an economic inefficiency between marginal quality costs and marginal quality benefits.

While the quality cost model is a useful economic tool for making quality management decisions, emphasis must be placed on two key points. First, optimum quality cost levels are not necessarily the optimum **economically competitive** quality cost levels. Deciding how much to spend on quality costs based solely on the quality cost model may fool management into thinking it has made the best decision because of the difficulty of measuring quality factors.

Second, the quality cost model assumes there is some degree of failure acceptable in the product or service. In most industries, standards and specifications suggest that there will be some failure. The critical nature of many industries such as NASA, however, require perfection to ensure the success of the entire program. This should be reflected in the cost of failure curve (Gates 1991). Managers may disagree about the level of quality required based on their perception of the nature their specific product or service. It is only with concrete data that these differences will be resolved.

The allocation of quality costs should be handled by the TQL organizations responsible for the processes affected by each cost. Information derived from the use of SPCs within the greater framework of total quality program are the manager's keys to the effective use of quality funds.

V. TRAINING

A. GENERAL

The purpose of this chapter is to provide the reader with a summary and analysis of SPC training currently in use in both the U.S. Navy and commercial industry. The programs analyzed are the Six Sigma Quality program at Motorola, Inc., and the SPC training programs at NAD Norfolk, NAD Alameda, and the Naval Construction Battalion, Port Hueneme. It is hoped that the diversity and varied scope of the programs presented during this chapter will provide a sound foundation on which to begin the formulation of an SPC training program at a naval telecommunications command.

B. BACKGROUND

Central in the quality theory of W.E. Deming is the concept of the "critical mass," a group of individuals highly knowledgeable of the theory of quality that eases the resistance to changes in philosophy. Essential to the development and expansion of this critical mass is the presence of a comprehensive training/education program. Of the fourteen points Deming views as being critical to achieving total quality, three deal directly with the issue of education and training.

Presently, the Navy's attempt at nurturing this "critical mass" is the Senior Leadership Seminar. Aimed at top-level managers (i.e., flag officers, base and large force commanders), the course is designed as an introduction to the basic concepts of the Navy's TQL program. Basic introductory training in the use of SPCs is given during the seminar.

TQL training specifically addressing SPCs is currently under development by the Navy's TQL Executive Steering Group for Education and Training. Tentatively titled "Basic Qualitative Methods and Tools for Process Improvement," the program focuses primarily on the seven basic graphic tools introduced in the third chapter. Particular emphasis is placed on the understanding and application of control charts in process improvement. The course, expected to become operational in mid-April 1992, resembles commercially available products such as The Memory Jogger Plus program developed by the Goal/QPC Corporation of Methuen, Massachusetts (Sniffen 1991). The course is tailored for a fleet-wide audience and is expected to be approximately five days in length (Sniffen 1991).

This initial training course addresses the need for basic standardized, instructional material. It does not, however, contain any advanced SPC methods such as those covered in the fourth chapter. The Navy, realizing the importance and universal applicability of the basic SPC tools, has decided to restrict its initial training solely to the basic SPC tools.

Realizing most of the advanced SPC methods are beyond the scope of the majority of fleet commands, the Navy plans to conduct advanced training only after the basic course is well established. The Navy's advanced SPC training will be targeted at cultivating an "advanced critical mass" of individuals (Sniffen 1991). These individuals would attend a Navy-sponsored advanced SPC course and then be assigned to commands where advanced SPCs are more readily applicable such as a Naval Supply Center or Naval Aviation Depot. The Navy feels this advanced training should be sufficient to address the fleet's need for advanced SPCs (Sniffen 1991).

For the telecommunications manager reporting to his new command interested in training their personnel in the knowledge and use of SPCs, the following descriptions of successful SPC programs should provide valuable information pertaining to the type, scope, and depth of SPC training required for their command.

C. DESCRIPTION OF TRAINING PLANS

1. Motorola, Inc.

a. Background

Motorola is one of the world's leading manufacturers of electronic equipment, systems and components. Its product line is varied, ranging from cellular telephones to semiconductors. Employing approximately 100,000 employees worldwide, Motorola is ranked among the 100 largest industrial

companies in the United States (Therrien 1991). Sales in 1990 totaled $9.6 billion (Lewis 1991). Contributing mightily to their worldwide success is Motorola's commitment to quality, personified in their Six Sigma Quality program.

Started in 1978, the goal of the Six Sigma program is the company-wide reduction of defects to a rate of 3.4 defects per million products (Therrien 1991). To achieve this goal, Motorola has invested heavily in the training and education of its employees with particular emphasis on the knowledge and use of SPCs.

b. Training

Through its educational facility, Motorola University, Motorola has developed a three-pronged training program to introduce and educate Motorola employees to SPCs. Initially concentrating primarily on its manufacturing and engineering employees, SPC training now caters to administrative employees as Motorola strives to achieve "Six Sigma" company-wide (Prins 1992). The SPC training program is broken down into three phases: SPC Core I, II, and III.

(1) SPC Core I. Comprised of seven individual courses totaling over 24 hours of instruction, this core focuses primarily on data collection techniques and graphical means of displaying this information such as cause and effect diagrams and pareto charts (Motorola 1991). These fundamental

concepts are stressed at Motorola because "you can't run until you know how to walk" (Prins 1992).

(2) SPC Core II. Comprised of seven courses and 36 hours of instruction, this core deals with more complex SPC issues such as process capabilities and histograms. Process control charts are also covered in depth. An elementary course in statistics covering topics such as deviation and variation is a prerequisite to entering this core of training (Motorola 1991).

(3) SPC Core III. This final core is also the most advanced, consisting of over 15 days of instruction in such advanced SPC issues as fractional factorial and full factorial analysis (Motorola 1991).

A listing of the individual courses comprising each core of the training syllabus is seen in Figure 29.

c. Scope

SPC training is made available to any employee whose job responsibility involves identifying and reducing causes of variation to achieve quality goals (Motorola 1991). SPC Cores I and II are part of the training syllabus for <u>all</u> employees in the manufacturing engineering, management, support and supervision curriculums (Motorola 1991).

In addition to the company-wide commitment to quality through education, Motorola's quality commitment extends to suppliers. In SPC-373, Introduction to Techniques

Core One:	SPC 360	SPC Overview
	362	Data Identification
	364	Data Collection
	366	Data Display
	368	Pareto Diagrams
	370	Cause and Effect Problem Analysis
	372	Multi-Vari Analysis
Core Two:	SPC 374	Statistics I
	376	Histograms
	378	Process Capability
	380	Variable Control Charts
	382	Measurement System Analysis
	384	Attribute Control Charts
	386	Precontrol
Core Three:	SPC 388	Statistics II
	390	Non-Parametric Comparative Experiments
	392	Full Factorial Experiments
	394	Fractional Factorial Experiments
	396	Component Search

Figure 29 Motorola'a Six Sigma SPC Curriculum

for Phased Process Quality Improvement, Motorola provides SPC training to suppliers in an effort to achieve total customer satisfaction through the application of SPC techniques that support implementation of Six Sigma quality and total cycle time reduction (Motorola 1991).

While it is difficult to directly correlate Motorola's corporate success to the Six Sigma quality program, Motorola has experienced a steady increase in revenue and net income since its inception in 1978. This has been despite

increases in competition in Motorola's markets. Specific quality success stories are numerous and varied.

In manufacturing, Motorola has improved output 150 fold, with defects expected to drop from an average of 6000 per million in 1986 to an average of 40 per million by yearend (Therrien 1991). The time to assemble a Motorola Mini-Tac cellular telephone has been reduced by 97 percent (Alster 1987).

Process improvement measures have also been implemented in administrative procedures. Process improvements such as clearer directions on forms and an easy-to-use format for computer screens have enabled Motorola's corporate finance department to reduce the time to close their monthly books from twelve to four days (Therrien 1991). In one of Motorola's order processing operations, process improvement led to entry errors dropping from 625 to 63, resulting in a savings of over $1.7 million (Buetow 1989).

2. Naval Aviation Depot, Norfolk

a. Background

NAD Norfolk is one of six depots that repair, overhaul and modify military aircraft. TQL training stressing SPCs has been ongoing since 1985 (Sutton 1992). The success of NAD Norfolk's efforts in this area is evidenced by the depot receiving the United States Senate Productivity Excellence Award in 1988, given annually to the government

organization demonstrating superior efforts in the achievement of efficiency and quality (Ward 1991).

b. Training

SPC training at NAD Norfolk consists of a 10 module, 24 hour course focusing on basic mathematics skills, the seven basic graphic tools and an introduction to Deming's PDCA cycle. The syllabus was developed in house with outside assistance from GOAL/QPC and is taught by a SPC facilitator at NAD Norfolk (Sutton 1992).

c. Scope

Originally limited to supervisors and managers, SPC training has expanded to include production workers. The attitude of the employees has been extremely favorable. This is evident from numerous requests for more workspace specific SPC training. This interest has resulted in the development of "roving SPC training", a supervised form of OJT on the use of SPCs in the workspace (Sutton 1992).

3. Naval Aviation Depot, Alameda

a. Background

NAD Alameda, like NAD Norfolk, is also tasked with the repair, overhaul and modification of military aircraft. Its SPC training syllabus has been in place since 1988 (Mattoon 1992).

b. *Training*

The training syllabus consists of two four-hour segments. The first four hour segment presents a basic overview of SPC, focusing on the seven basic graphic tools (Alameda 1992). The second four hour segment concentrates on in-depth instruction and training on control charts as well as an introduction to more advanced SPC tools, specifically Taguchi methods (Alameda 1992). Both training segments rely heavily on practical exercises to allow the individual to become more familiar with and comfortable in the use of SPCs. The syllabus was developed with the assistance of a quality consultant and is taught by the TQL facilitator at NAD Alameda (Mattoon 1992). The syllabus itself is a process under constant analysis by the NAD TQL Quality Management Board (QMB) of which the head SPC facilitator is a member (Mattoon 1992). A subject breakout of the two segments is contained in Figure 30.

c. *Scope*

The initial four hour training segment has been incorporated in NAD Alameda's TQL training and is received by all command personnel (Mattoon 1992). The second segment, dealing with more advanced, production-specific methods, is aimed primarily at engineering and production supervisors and engineers (Mattoon 1992). This training has lead to the streamlining of numerous repair and administrative procedures

General Training
Introduction to SPC
Variation
Data Collection
Pareto Analysis
Run Charts
Control Charts

Engineering Training
Data Collection
Flow Charts
Pareto Diagrams
Cause and Effect Diagrams
Histograms
Scatter Diagrams
Run Charts
Control Charts
Control Chart Analysis
Taguchi Methods

Figure 30 SPC Training Syllabus for NAD Alameda

at NAD Alameda resulting in the reduction of lost manhours due to rework at the command (Mattoon 1992).

4. Naval Construction Battalion, Port Hueneme

a. *Background*

The Naval Construction Battalion at Port Hueneme, California is tasked with the development and construction of military facilities throughout the entire West Coast. The command has been involved in TQL and SPC training since 1989 (Bradford 1992).

b. Training

The SPC curriculum consists of a 16 hour training program focusing on the use of the seven basic graphic tools (Bradford 1992). Particular emphasis is place on the use of control charts to monitor process performance. The curriculum was developed in conjunction with the Goal/QPC Corporation (Bradford 1992). Training is presented by a facilitator from Goal/QPC with facilitators from Port Hueneme expected to take over these duties in May 1992 (Bradford 1992). Port Hueneme plans to expand its training to include more advanced SPC methods, specifically Taguchi methods and systems analysis by June 1992 (Bradford 1992). Figure 31 shows the individual subjects covered in the SPC syllabus and the amount of instruction given.

Flowcharting (1 hr)

Check Sheets (1 hr)

Pareto Charts (1.5 hr)

Cause & Effect Diagrams (1.5 hr)

Run Charts (1 hr)

Histograms (1 hr)

Scatter Diagrams (1 hr)

Control Charts (8 hr)

Figure 31 SPC Training Syllabus for Port Hueneme

c. *Scope*

The initial groups targeted for SPC training were the two upper echelons of the command's TQL structure, members of the Executive Steering Committee (ESC) and the QMB. Presently, all members of the command's Process Action Teams (PAT) have also have received this training (Bradford 1992).

D. ANALYSIS OF TRAINING PROGRAMS

Analysis of the SPC training programs yields five points that should be of particular interest to telecommunications managers investigating the possibilities of applying SPCs to their commands. These points deal with the scope, content and effectiveness of SPC training.

Regardless of the size or sophistication of the training programs, all programs reviewed stressed the importance of the fundamental SPCs. These form the building blocks to implement SPCs into a command or to expand into more complex SPC tools. From the multi-million dollar Six Sigma program at Motorola Inc. to the comparatively modest training offered at Port Hueneme, the importance of the seven basic graphic tools cannot be overstated. While technology has allowed SPCs to become more complex and sophisticated, tools such as cause and effect diagrams, pareto charts and control charts continue to provide a simple, easy to understand means of improving processes.

In all four training programs presented, education of the vast majority of the company/command was a top priority. Some reasons for this policy include:

- The use of SPCs represents a fundamental change in the managerial style of all the companies/commands reviewed. To ensure a smooth and receptive transition towards SPCs, general training of SPCs provides the employee a better understanding of and more familiarity with the tools. Familiarity removes the hostility frequently associated with a change process. This has been particularly true in the case of the NAD Norfolk SPC program where employee education has resulted in program expansion.

- Training which targets a wide audience adds to the "critical mass" of individuals present within the company/command.

- Training on a command/company wide basis combats against the potential reduction in the "critical mass" due to personnel transfers. This is of particular importance to naval commands.

While SPCs are a tool for management to improve the performance and quality of a process, they alone are not the answer. In this regard, SPCs provide management with data and information concerning processes. In order for SPCs to achieve their full potential, they must be used within the context of the Total Quality Leadership program presently being implemented throughout the U.S. Navy. All of the SPC training programs reviewed were but a part of a larger quality movement present in the company/command. Managers acting solely on information gained from SPCs are essentially reverting back to the failed Management By Objective style of leadership.

Finally, with the exception of the Motorola Six Sigma program, every SPC program analyzed received assistance from an outside consulting source. This was mainly due to the fact that most Naval commands had no experience with SPCs. Realizing the economic burden this placed on commands, the Navy is developing basic SPC training to replace the need for outside consultants. Naval telecommunications commands are expected to participate fully in the Navy-wide SPC training. Because this training is not yet fully implemented, no telecommunications commands were far enough into the TQL program to provide any unique SPC training information.

VI. CASE ANALYSIS AND SUMMARY

A. GENERAL

The tools and training plans presented in this thesis represent a means for managers to systematically improve service processes. As both a summary of the material presented and an exercise in the selection of applicable SPC's, a case study is provided. While not implicit in the discussion of the case, the entire quality improvement process must be framed by an active and completely supported TQL structure and philosophy.

B. SCENARIO

The setting is a fictitious shore-based naval organization operating within the framework of an established TQL program. The Telecommunication System Manager (TSM) is faced with budget cutbacks and an AUTOVON telephone system that is widely regarded with derision. These cutbacks have raised suspicions that the implementation of the AUTOVON replacement, FTS2000, will be delayed. The TSM is dedicated to providing the best possible service to the hundreds of users of AUTOVON. The Executive Steering Committee has identified complete and unhindered access to and use of the telephone network by members of the command as a top priority. This goal is in support of the command's mission to conduct outstanding Navy-

wide research. The command is not expected to change in size in the next few years and there is no funding available for AUTOVON network improvement. The Quality Management Board further narrows the ESC's goal and targets improvement of the AUTOVON system to achieve the ESC's overall quality goal. A Process Action Team (PAT) is formed to collect and summarize process data and identify potential areas for quality improvement.

Using flowcharts and cause and effect diagrams, the PAT identified several potentially significant variables in the AUTOVON phone call process. The flowchart and cause and effect diagram are shown in Figures 32 and 33 respectively.

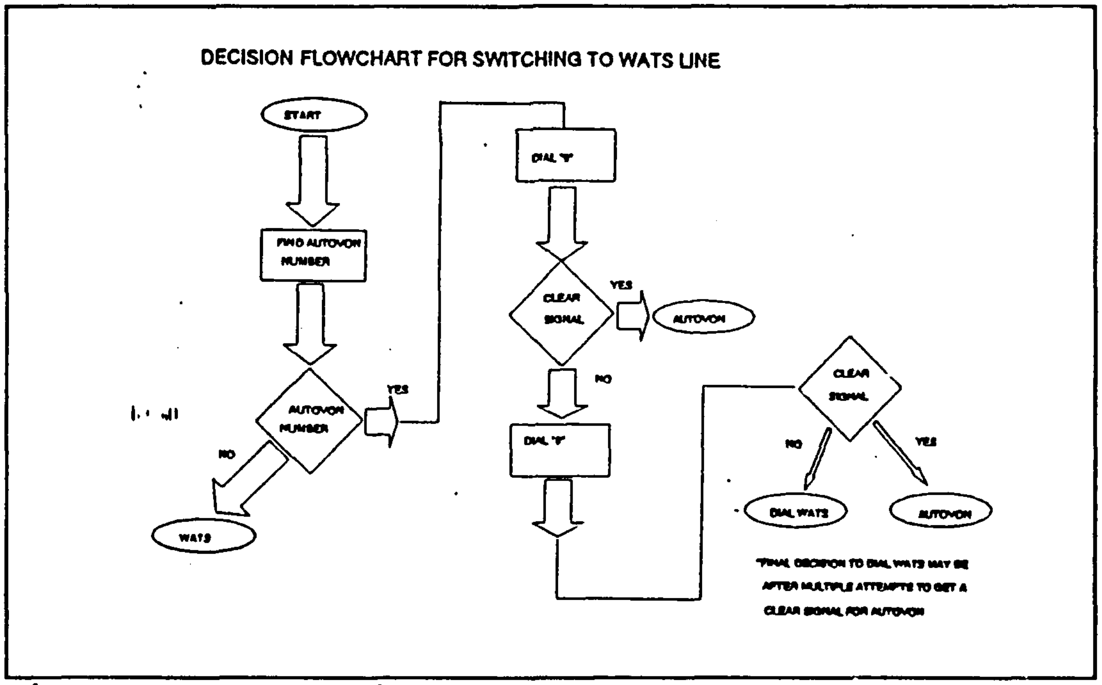

Figure 32 AUTOVON Flowchart

Of particular interest to the PAT were the possible effects of phone availability, busy circuits and users switching to more

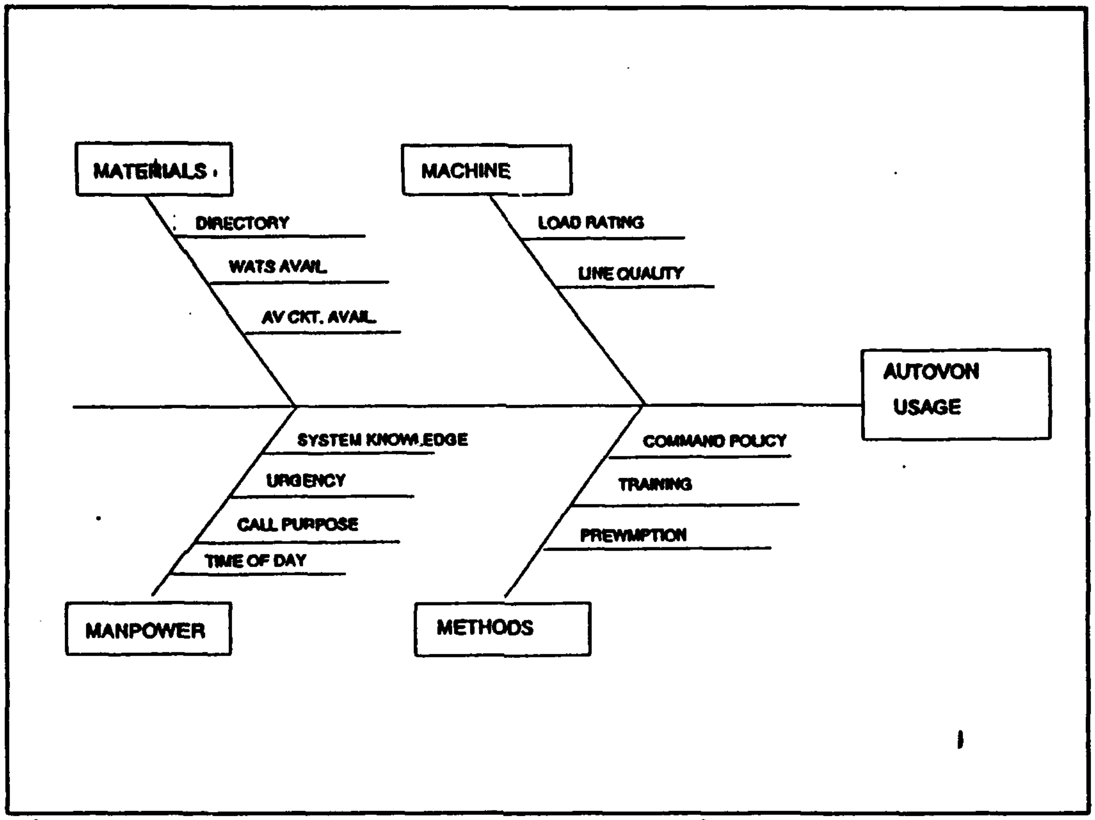

Figure 33 AUTOVON Cause and Effect Diagram

expensive WATS circuits on overall AUTOVON usage.

At this point data must be collected to assist the PAT in determining which variables were most significant. A survey asking a variety of questions about AUTOVON usage revealed data shown in the Pareto chart shown in Figure 34. Again, the busy signal problem appears most significant.

1. **Process Capability**

The PAT decides to study AUTOVON process capability using time to a clear signal as a response variable. The X & MR chart is chosen for the following reasons:

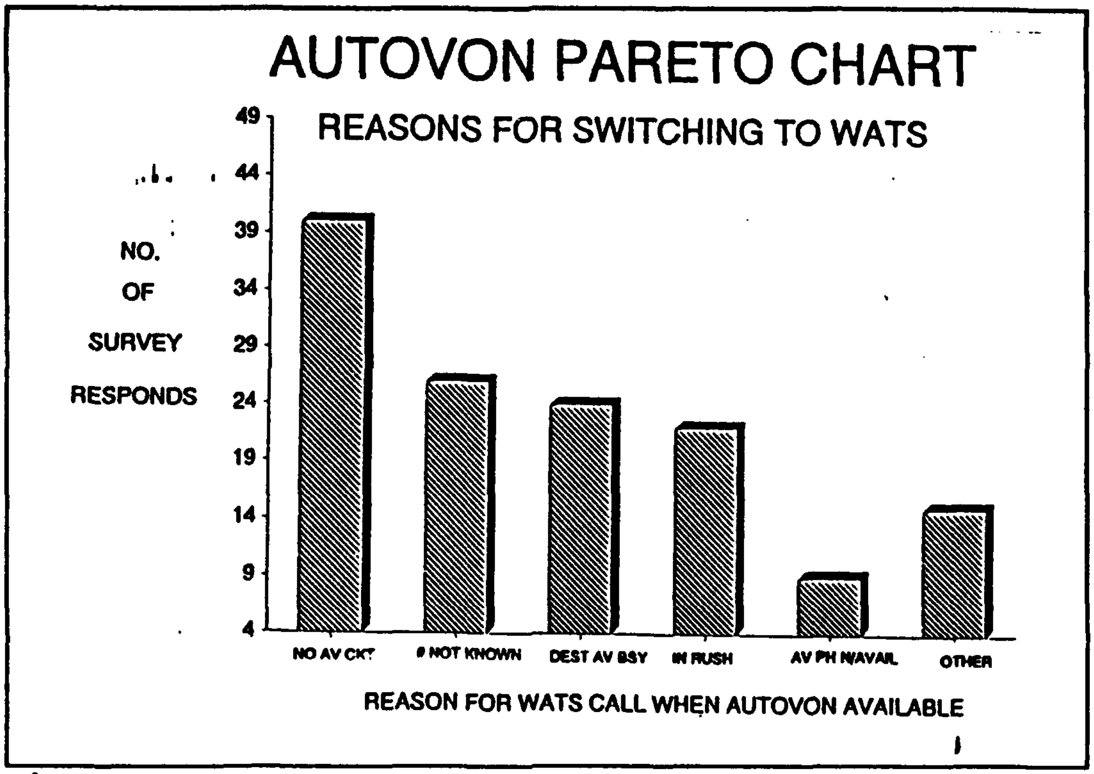

Figure 34 AUTOVON Pareto Chart

- An average time to a clear signal survey system is simple to administer. Since the sample size will vary by the hour, the X-Bar chart is not possible.
- The PAT is reasonably sure that the values will approximate a normal distribution.
- The effects of explanatory variables can be analyzed using an X & MR chart.

Using commercially available software on a Navy issue PC, the PAT performs a capability study as shown in Figure 35. In the first phase, the original data points for each hour are plotted and control limits are calculated. Each data point represents the average time to a clear circuit. Initial process analysis reveals a single data point outside the control limits. This point is noted for further investigation

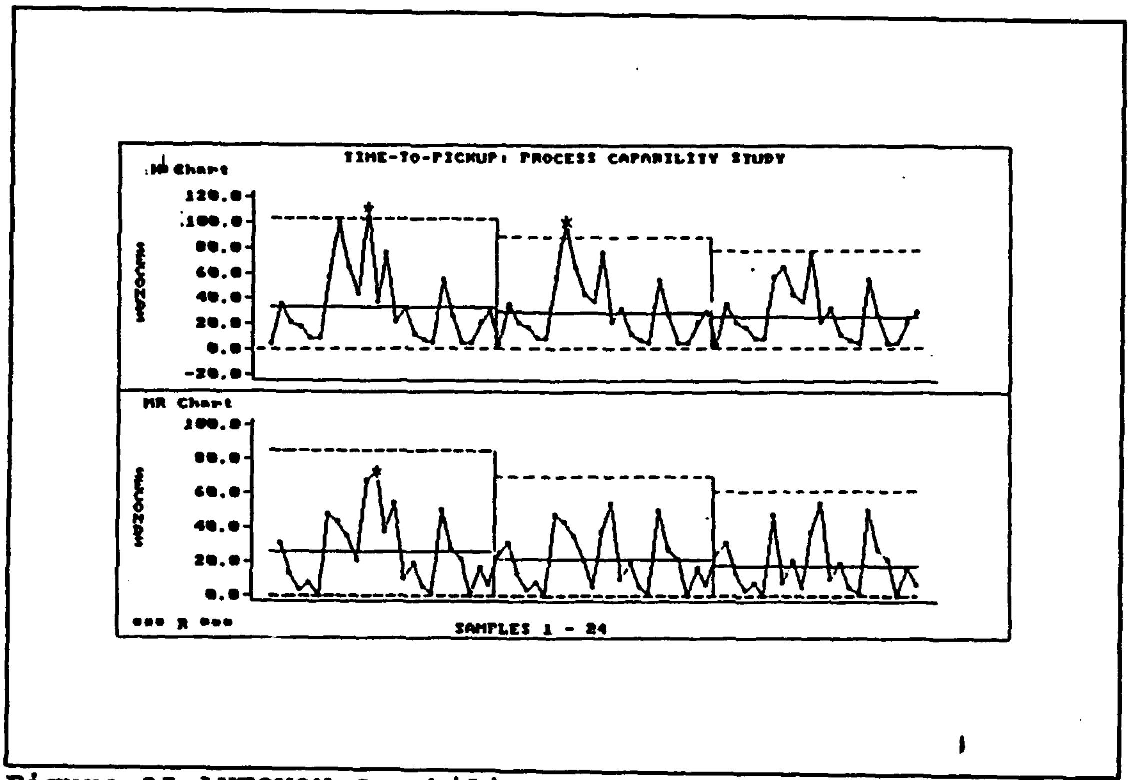

Figure 35 AUTOVON Capability

and intentionally dropped from the data set.

A new set of control limits using the remaining data points are calculated. The limits are tighter and the average is lower. The tighter limits put a different point out of control. Again, this data point is noted for further investigation and dropped from the data set.

The PAT uses the remaining data to calculate new control limits. With no points out of the limits, the chart shows the process to be in control. The variability of the process is decreased as evidenced by the tighter control limits. The average time to a clear signal is also lower.

The sources of the two out of control points are now investigated. More data is collected using the expertise gained by the PAT to pinpoint specific causal factors. The PAT notes from a run chart that the demand for circuits can saturate the system during overlapping business hours with the Eastern time zone (This command is in California). Based on this information the QMB makes a recommendation to the ESC to make AUTOVON lines available to researchers during non-normal working hours. The second out of control point reflected reaction to the result of an unplanned system outage due to a construction crew's destruction of telephone cabling on the station property. This is an example of special cause variation. The incident was investigated by the Public Works Department and underground cable markings were constructed where necessary.

After the two changes were implemented, data was again collected, revealing process limits and averages consistent with the capability study.

2. Process Control

Using the control limits determined in the process capability study, data points were plotted to monitor process performance. In Figure 36, the last point is out of control. Investigation into the source of the out of control condition reveals that none of the new researchers or employees were briefed about the all hours AUTOVON phone access program. To

correct this out-of-control condition, this information was put into the indoctrination program for new employees and one time training for the newest employees was performed by the command. In this case, the PAT was keeping the process operating within its statistical limits, not defining a new capability level. For this reason, new control limits are not calculated. The process is continually monitored to ensure that out-of-control situations can be detected and corrected.

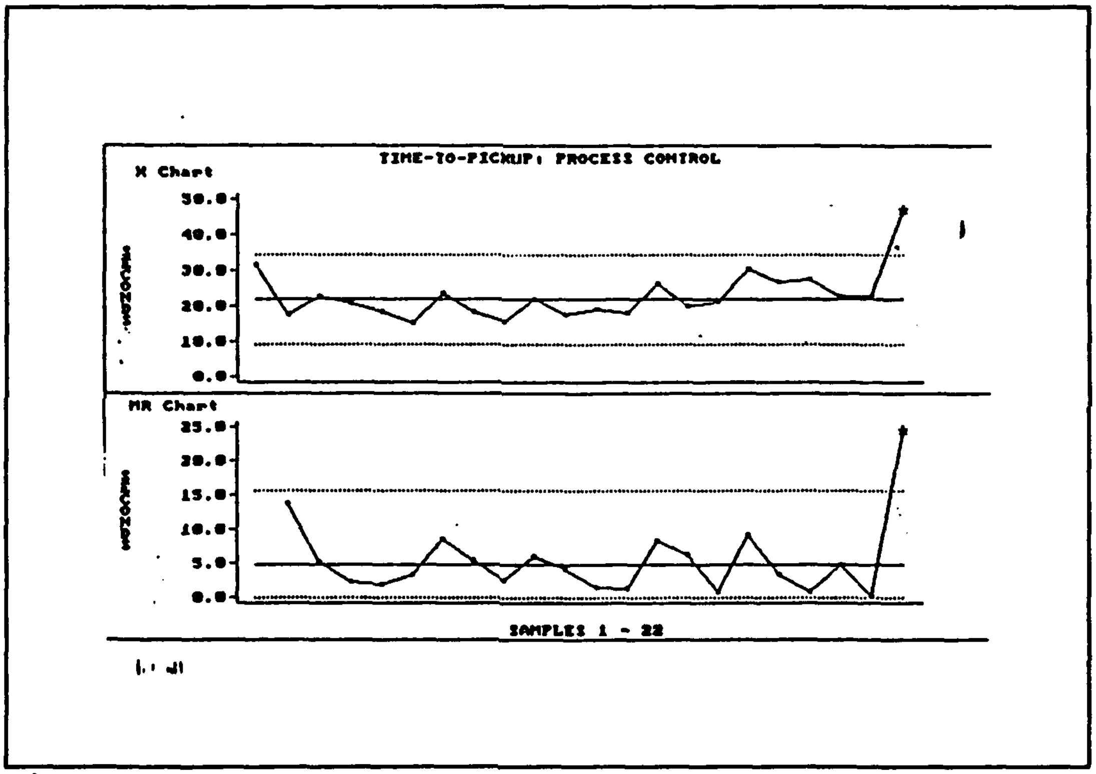

Figure 36 AUTOVON Process Control

At this point it can be useful to compare the standard deviation of the process to the customer-defined specifications for quality. This comparison can be made as long as the process is under control. Ideally, the command

would, through various data collection means, be able to identify how the customer defines quality. For analysis purposes, the user specification of quality is a wait of less than 20 seconds to a clear signal.

3. Process Improvement

There are two possible reasons for improving this process. First, it may not satisfy the customer specification as indicated above, or the process is in control but the average time to a clear signal (central tendency) is still at an unacceptable level. At this point, the most obvious options appear to be expensive equipment improvements such as updating the switching capability or adding circuits to the existing system. The PAT again collected and analyzed data to find ways of reducing the busy signals and discovers a possible relationship between the percentage of abandoned AUTOVON attempts and the level of use of the out-WATS lines. A regression analysis of the relationship that shows a positive correlation between the two variables is shown in Figure 37. If the time to a clear signal is reduced below 20 seconds, then the WATS usage is significantly decreased. This information was presented to the QMB and provided the evidence needed to miraculously "find" funds to update the switching equipment and add AUTOVON lines.

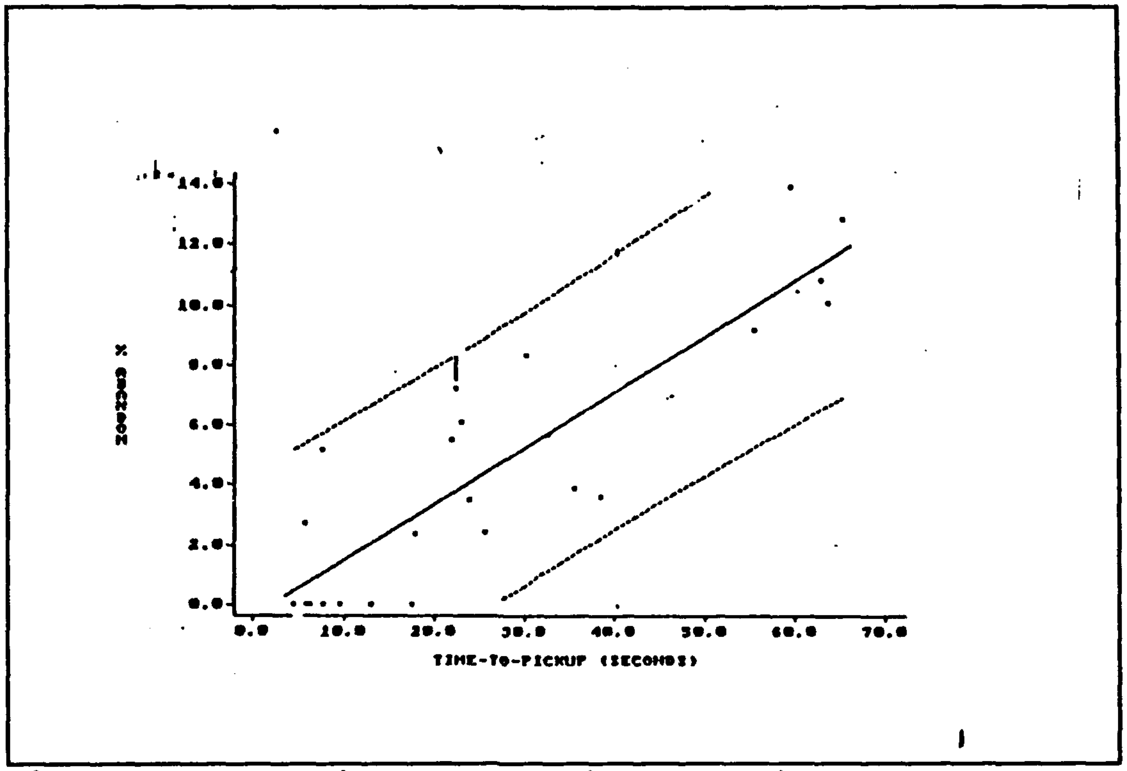

Figure 37 Clear Signal Regression Analysis

C. CASE STUDY CONCLUSIONS

The case analysis provides a framework from which the communication systems manager can relate SPC's to communications issues within the structure of a typical Navy organization. The potential for application of the basic SPCs cannot be overstated. Because selection of SPC charts and tools is largely scenario dependent, several of the tools presented in the thesis were not included in the case. Their ommission in the case study in no way understates their potential for application to telecommunications issues.

D. THESIS SUMMARY

This thesis was written to provide personnel reporting to a command that deals with both TQL and naval communications a familiarity with basic and advanced statistical techniques, economic relationships between quality and cost, and the scope of SPC training currently in use. Descriptions and telecommunications applications of basic and advanced SPC tools were presented throughout the thesis. Descriptions of SPC training programs currently in place were provided to give personnel an understanding of the level of training required in telecommunications related commands. The final chapter provided a sample case analysis using basic SPCs to illustrate an integrated application of the tools and emphasize the potential for application of all the SPCs presented.

LIST OF REFERENCES

[Alameda] (No author given) TQL Training Syllabus for NAD Alameda 1992.

[Alster] Alster, Norm. "Calling All Competitors: Motorola Just Got Tough," Electronic Business. December 1987.

[AT&T] American Telephone and Telegraph Co. Analyzing Business Process Data: The Looking Glass, AT&T Technical Publications Center, 1990.

[Bradford] Interview between C. Bradford, Training Department Supervisor at Naval Construction Battalion Port Hueneme and J. Beadles, 26 January 1992.

[BSI] British Standards Institution, Guide to the determination and use of quality related costs, 1981.

[Buetow] Buetow, Richard. Fifty Minute Quality Speech. Motorola, Inc. 1991.

[CNO] Chief of Naval Operations Message: Navy Fleet-wide Implementation of TQL, 022224Z Oct 1991.

[Deming] Deming W. E. Out of the Crisis, Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, MA, 1986.

[Dockstader] Dockstader, S.L. and A. Houston. A Total Qality Management Process Improvement Model, Naval Personnel Research and Development Center, December 1988.

[Dyer] Dyer, C. "On-Line Quality: Shigeo Shingo's Shop Floor", Harvard Business Review, January-February 1990.

[FP&L] Florida Power and Light Co. Statistical Concepts for Managers. Miami, FL, 1989.

[Gates] Gates, W. Class Notes for CM3002 Economic Issues in Telecommunications, Winter 1991.

[Gitlow] Gitlow, H. and A. Oppenheim. Tools and Methods for the Improvement of Quality, Irwin, Homewood, IL, 1989.

[Heagy] Heagy, C. "Determining Optimal Quality Costs By Considering the Cost of Lost Sales," Journal of Cost Management for the Manufacturing Industry, Fall 1991.

[Howard] Howard, J.D. "Total Quality Management: The View from the Top." Defense, January-February 1991.

[Ishikawa] Ishikawa, K. Guide to Quality Control. Tokoyo: Asian Productivity Organization, 1983.

[Lewis] Lewis, E. and B. Mims. "The Corporate Elite," Business Week, 19 October 1990.

[Mattoon] Interview between M. Mattoon, TQL Facilitator at NAD Alameda and J. Beadles, 14 January 1992.

[Motorola] (No author given) Motorola University Catalog of Training and Education Programs and Services, Motorola Inc., Schaumburg, IL, 1991.

[Nolan] Nolan, T. and L.P. Provost. "Understanding Variation", Quality Progress, May 1990.

[Port] Port, O. "How to Make It Right The First Time," Business Week, 8 June 1987.

[Prins] Interview between Dr. J. Prins, Manager, Research and Development, Motorola Six Sigma Research Institute and J. Beadles, 27 January 1992.

[Roslund] Roslund, J. Evaluating Management Objectives with the Quality Loss Function, Quality Progress, August 1989.

[Ryan] Ryan, T. Statistical Methods for Quality Improvement, John Wiley & Sons, New York, NY, 1989.

[Scherkenbach] Scherkenbach, W. The Deming Route to Quality and Productivity, Ceep Press, Washington D.C. 1990.

[Sniffen] Interview between R. Sniffen, Navy Personnel Research and Development Center, Quality Support Center, Norfolk, Virginia, and L.Schonenberg, 17 November 1991.

[Sutton] Interview between K. Sutton, TQM Statistician at Norfolk and J. Beadles, 18 January 1992.

[Taguchi & Clausing] Taguchi, G. and D. Clausing. "Robust Quality", Harvard Business Review, January-February 1990.

[Therrien] Therrien, L. "Spreading the Message," Business Week, 25 October 1991.

[Trietsch] Trietsch, D. Class Notes MN4377 TQM/TQL: Philosophy, Theory, Tools, Spring 1992.

[Walton 1986] Walton, M. The Deming Management Method. Perigee Books, New York, NY, 1986.

[Walton 1991] Walton, M. Deming Management at Work. Perigee Books, New York, NY, 1991.

[Ward] Ward, J. and C. Behr. TQL Source Guide. Naval Personnel Research and Development Center. San Diego, CA. 1991.

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